SWINBURNE
SENIOR SECONDARY COLLEGE

Biology
Holiday Homework
Year 12, 2022

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Work required in preparation for start of 2021:	Complete questions 1-16 of Edrolo: Chapter 1 (This is part of your Coursework requirement for Semester 1) These are **due in Term 1, Week 2 of 2022**
Textbooks and other resources:	Prescribed textbook: Edrolo Biology Unit 3&4 (digital or print copy) Coursework mind-maps: to be printed for students for each AOS
Key Links:	**VCAA Biology page** The Biology Study Design, past exam papers and assessment information are all located here. Useful websites: • GTAC - Gene Technology Access Centre • VCE BIology - ATAR notes • RCSB Protein Data Bank

Course Overview

Unit 3: How do cells maintain life?	
AOS 1 – Nucleic Acids & Proteins to maintain life **SAC – 50% (40 marks)**	**AOS 2 – Regulation of biochemical pathways** **SAC – 50% (40 marks)**
• The relationship between nucleic acids and proteins • DNA, RNA, gene expression • Gene regulation - *trp* operon • DNA manipulation techniques and applications • CRISPR-Cas9 gene editing • GMOs and transgenic organisms	• Regulation of biochemical pathways in photosynthesis and cellular respiration • Function of enzymes in biochemical pathways • Photosynthesis as an example of a pathway • Cellular respiration as an example of a pathway • Biotechnological applications of biochemical pathways

**School-assessed Coursework for Unit 3 will contribute 20% to the study score (total 80 marks)*

Unit 4: How does life change and respond to challenges?		
AOS 1 – Organism responses to pathogens **SAC – 33%**	**AOS 2 – Species relatedness over time** **SAC – 33%**	**AOS 3 - Student-directed scientific investigation** **SAC – 33%**
• Responding to antigens • Innate (non-specific) immune response • Acquiring immunity • Adaptive (specific) immune response • Disease challenges and strategies • Vaccine programs	• Genetic changes in a population over time • Selection pressures and mutations • Changes in species over time • Determining the relatedness of species • Evidence for evolution • Human change over time	• Investigation design • Variables and methodologies • Scientific evidence • Organising and evaluating data • Identifying sources of error • Science communication • Using scientific terminology • Conventions for scientific poster presentation

**School-assessed Coursework for Unit 4 will contribute 30% to the study score (total 120 marks)*

What are Units 3 & 4 Biology all about?

As part of Biology in Units 3&4 you will explore the diversity of life as it has evolved and changed over time, and consider how living organisms function and interact.

In Unit 3,you will investigate the workings of the cell from several perspectives - from biochemistry and DNA manipulation to the functioning and regulation of biochemical pathways within cells.

In Unit 4, you will consider the continual change and challenges to which life on Earth has been, and continues to be, subjected to - including responses to pathogens and how species have evolved to change over time.

To be judged Satisfactory for this subject you will need to:

- Attend classes regularly
- Pass all SACs
- Complete required coursework for **all outcomes**
- Engage and participate in class
- Participate in regular group practical activities
- Keep an up-to-date and accurate logbook of practical activities

CHAPTER

1

General skills

The key science skills and ethical understandings are a core component of the study of VCE Biology and apply across Units 1 to 4 in all areas of study. In designing teaching and learning programs for each unit and in assessing student learning for each outcome, teachers should ensure that students are given the opportunity to develop, use, and demonstrate these skills in a variety of contexts, including when undertaking their own investigations and when evaluating the research of others. As the complexity of key knowledge increases from Unit 1 to 4, and as opportunities are provided to undertake scientific investigations, students should aim to demonstrate the key science skills at a progressively higher level.

1A KEY SCIENCE SKILLS

If you were at school in Australia in Year 7 or 8, at some stage you would have found yourself in a line of students waiting to receive a vaccination for the human papillomavirus (HPV). How did you feel about this? Happy that you got to miss a bit of class? Or did you have to blink back tears of anxiety?

HPV can cause genital warts and a number of cervical and anal cancers. The HPV vaccine is taken in two doses six months apart and became free for school students in 2007 as part of the National HPV Vaccination Program. Before this program was introduced, four out of every five people contracted HPV at some stage in their life. Now, as a result of the vaccine:

- *cases of genital warts have decreased by 90% in people under 21*
- *90% of cervical cancers and 96% of anal cancers will be prevented*
- *Australia is set to be the first country in the world to eliminate cervical cancer.*

So how did the scientists make this powerful vaccine? Did they mix random concoctions of chemicals together with the hope they might destroy the virus? Did they hold up beakers of coloured water to the light and peer seriously at them like some mad scientist? Or were they following an age-old, systematic process of discovery?

This won't hurt a bit...
Image: Embrace of Beauty/Shutterstock.com

Lesson 1A

In this lesson you will learn the key science skills (KSSs) required to plan, conduct, analyse, and present the results of scientific investigations.

◀ *Prerequisite knowledge* *Future applications* ▶

Years 7–10
You've followed the scientific method, written practical reports, and identified variables before. Now, you need to build on those foundations to broaden and deepen your science skills.

Year 11
In Year 11, you were first introduced to these key science skills and applied this knowledge to concepts such as the plasma membrane, homeostasis, and body systems.

Lesson 1B
None of the skills in this lesson can be used if your investigation is unethical – in lesson 1B, you'll learn how to identify and analyse bioethical issues.

Year 12
The skills taught in this lesson are applicable across the VCE Biology course, and will be assessed in many of your SACs and exams.

Study design dot points

- develop aims and questions, formulate hypotheses, and make predictions
- plan and conduct investigations
- comply with safety and ethical guidelines
- generate, collate, and record data
- analyse and evaluate data and investigation methods
- construct evidence-based arguments and draw conclusions
- analyse, evaluate, and communicate scientific ideas

Key knowledge units

What are key science skills?	0.0.0.10
Designing and planning investigations	0.0.0.11
Conducting investigations	0.0.0.12
Analysing and presenting results	0.0.0.13

What are key science skills? 0.0.0.10

OVERVIEW

Key science skills are the capabilities students demonstrate when designing, conducting, analysing, and presenting scientific investigations.

THEORY DETAILS

What are key science skills and why are they important?

Key science skills (KSSs) are a set of capabilities that VCE Biology students are expected to learn over Units 1–4 (listed on pages 7 and 8 of your study design). You can use KSSs in all realms of life, however, and not just in the Biology exam. This is because, at its most fundamental level, science is about discovering the truth in the world around us – which is clearly something we should all be doing!

key science skills (KSSs) the set of capabilities that VCE Biology students must learn to design, conduct, analyse, and report valid experiments

You demonstrate KSSs when you ask questions like:

- do I believe this? Why?
- what evidence supports this conclusion?
- is this evidence trustworthy?
- is it weak or strong evidence?
- is there evidence that undermines this conclusion, or supports another position?

When your friend gossips to you about their neighbour, or your grandad complains that 'kids these days are spoilt', or you read a tweet from your favourite celebrity – you can ask these questions to decide for yourself what to think.

You will use KSSs more rigorously and methodically in your VCE science subjects. In these classes, you will learn to distinguish between weak (e.g. an **opinion**) and strong (e.g. data from a well-designed **controlled experiment**) evidence. You will also collect, analyse, and draw conclusions by:

- designing your own investigation/s, or
- examining someone else's investigation/s.

opinion the personal belief or viewpoint of an individual which typically has not been verified as fact

controlled experiment an investigation into the effect of an independent variable on a dependent variable, while keeping all other factors constant

reliable describes an experiment, tool, or measurement that produces similar results when repeated and reproduced

bias an inclination to favour a particular position or outcome

error differences between observed values and the true value

Less formal evidence, such as anecdotes and expert opinions, can be helpful to consider when drawing conclusions. However, data gathered from investigations that are guided by KSSs is broadly considered more 'trustworthy' and **reliable**. This is because KSSs help you to reduce **bias**, minimise the effects of **errors**, and ensure results are not due to chance.

The rest of this lesson will walk you through the KSSs you can use to design and examine scientific investigations. Whilst there are many different types of scientific investigations, we'll mostly focus on controlled experiments, which allow scientists to manipulate specific variables and control their studies to a high degree. You can be asked to demonstrate KSSs in SACs and on exams, so we have included KSS questions at the end of every lesson in this book.

Example

ACING VCE BIOLOGY

Let's say you want to use your newly developed KSSs to answer an age old question – how do you ace VCE Biology? How does one even use KSSs to answer this? Some scientific investigations you could undertake to answer this question include:

- surveying top-performing VCE Biology students from the previous year, collecting data on study habits and lifestyle
- analysing the research of other scientists and coming to your own conclusions based on the strengths and weaknesses of their investigations
- setting up an experiment where one group of students tries one study technique, and another does not try it, then comparing the marks they get on a test.

Theory in context

FRAMEWORKS FOR KNOWING WHAT IS 'TRUE'

Using KSSs to arrive at knowledge is often tied to ideas around the 'scientific method', which has characterised how many cultures around the world have approached natural science since the 17th century. However, the stringent adherence to KSSs is only one particular means of determining what is 'true'.

Other ways of seeking the truth can provide a more holistic approach to knowledge. For example, Indigenous Australians have a much longer history of developing knowledge which is often focused on the interconnections between individuals, habitats, and ecosystems. An example of this holistic, or 'big picture' knowledge of Indigenous Australians is fire management. According to Koori Country Firesticks (2017), Aboriginal fire management removes ground vegetation using cool burns that move slowly over small areas, taking place up to several times a year. This:

- reduces the fuel load
- protects the canopy of trees (so fruits and seeds are preserved; insects, birds, and climbing mammals have a place to hide; and shade is maintained after the fire)
- doesn't burn hollow logs (maintaining habitat)
- moves slowly so animals can escape
- manages weeds
- results in quicker return of native plants to the area.

Furthermore, the practice allows easier access to **Country**, cleans up important pathways, maintains cultural responsibility, and is part of ceremonies. In contrast, European 'hazard reduction burns' tend to involve hotter and less frequent fires that have the single goal of reducing fuel load.

Many people are calling for the integration of KSSs and Indigenous knowledge. These people point out that Indigenous ways of knowing share many characteristics with KSSs. Both place importance on observation, questioning, **hypothesis** testing, experimentation, and application. Indigenous ways of knowing have scientific rigour through thousands of years of repetition, but can also change if new evidence arises. These methods of scientific inquiry enabled Australia's first peoples to thrive on this continent for many tens of thousands of years, in good health and in a sustainable way.

Want to learn more about the intersection between Indigenous knowledge and KSSs? Here are some places to start:

Watch – this 10 minute video by the ABC about cool burns youtube.com/watch?v=RM72NtXxyLs&feature=youtu.be

Listen – to this podcast about Indigenous knowledge and science audioboom.com/posts/5380644-why-western-science-urgently-needs-aboriginal-holistic-knowledge-to-tackle-21st-century-issues

Read – this article about flaws in research into hazard reduction burns theconversation.com/the-burn-legacy-why-the-science-on-hazard-reduction-is-contested-132083

Country an area that is traditionally owned and looked after by an Aboriginal language group or community, or by certain people within that group. The term may indicate more than simply a geographical area – it is also a concept that can encompass the spiritual meaning and feelings of deep connection and attachment associated with that area

hypothesis a testable statement that describes how experimenters expect the dependent variable to change as the independent variable changes

Designing and planning investigations 0.0.0.11

OVERVIEW

Designing a scientific investigation involves: constructing a research question and aim; identifying your independent, dependent, and controlled variables; formulating a hypothesis; selecting a methodology; designing a repeatable, reproducible, and valid method; following ethical and safety guidelines.

THEORY DETAILS

Constructing a research question and aim

Most scientists start investigations by noticing something unusual, or a pattern, in the world around them. They might notice that a particular plant has useful properties, students perform poorly on tests when hungry, or that birds fly around the MCG lights at 11 pm. Then, scientists need to narrow the scope of their inquiry down to one question that they wish to answer. Table 1 outlines the requirements for a **research question**.

research question a testable, achievable, and specific question that an investigation sets out to answer

Table 1 Elements of a research question

Research question must be	Explanation	Bad example	Good example
Testable	You must be able to measure the factors you are interested in.	'How do sea monkeys grow?	'What is the effect of salinity on the life cycle of sea monkeys?'
Achievable	The scientist must have the funding, ethical approval, and resources available to answer the question.	'What happens to test scores if we prevent all school students from eating on the day of a test?'	'What is the average test score for students at this particular school if they have fasted for 0, 4, 8, or 12 hours?'
Specific	Only particular individuals will be sampled at particular times and locations.	'Is bird behaviour affected by light pollution?'	'Is silver gull (*Chroicocephalus novaehollandiae*) nighttime behaviour affected by light pollution in Melbourne from June to September?'

Sometimes you need to do a bit more background research to settle on a final research question. You may even go through a few draft questions as you refine it to become more testable, achievable, and specific. From the research question, it is usually pretty easy to develop an **aim**. The aim is the objective of the investigation and typically starts with the word 'To'. For the research questions above, the aims would be:

- to determine if the salinity of water affects the duration of life cycle stages in developing sea monkeys
- to determine if fasting before tests affects student performance
- to determine if silver gull (*Chroicocephalus novaehollandiae*) nighttime behaviour is different in light-polluted Melbourne compared to non-light-polluted areas.

Note that, where required, we include scientific names for species in research questions and aims.

aim the objective of an investigation or experiment

Image: fishmonger/Shutterstock.com

Figure 1 Indigenous knowledge has made significant contributions to science, including the identification of potential new materials from native plants like spinifex grasses.

Example

HOW POWERFUL IS A POWER NAP?

If you're studying VCE Biology, you're probably quite keen to investigate if there is something you can do to improve your results on assessments. You might have lots of friends who swear by the 'cram' method before exams, where they try to fit as much information in their head in the minutes, hours, and days prior. Your mum, meanwhile, always tells you that 'if you have a problem, sleep on it' and that this will help you understand and solve it. Is there anything to either of these two learning strategies? Can either of them improve your memory and performance on tests?

Considering this, we devised a first version of a research question to investigate:

'Is cramming or napping a better study method?'

We realised pretty quickly that this research question has some problems:

- It's not testable – how do you measure if something is a 'better' study method?
- It's not specific – who is participating? What does cramming look like? How long do participants nap for?

From here, we worked on a second draft of a research question:

'Do Year 11 Biology students at this school remember more if they cram or nap for one hour after a class?'

This question was much more testable, given that a test can be administered to measure how much our research participants actually remember. It was also much more specific, given that the people being studied are identified as Year 11 Biology students from a certain school. We've also made the research question more achievable by making the duration of the experiment one hour and using easily accessible participants (rather than, for example, all VCE students in Victoria).

Using this information, devise an aim for the investigation:

Aim: _____

_____

Suggested answer
Aim: To determine if cramming or napping improves the memory of Year 11 Biology students at this school.

Identify independent, dependent, and controlled variables

Notice that creating a testable, achievable, and specific research question means that investigations tend to end up measuring the effect of one variable on another variable. The variable that is being affected is the **dependent variable (DV)**, while the variable that is being manipulated is the **independent variable (IV)**. We can identify the IVs and DVs in the research questions we looked at previously:

- DV – duration of life cycle stages; IV – water salinity
- DV – test score; IV – time spent fasting prior to test
- DV – seagull nighttime behaviour; IV – light pollution or no light pollution.

A **controlled variable** (also known as a constant variable) is a factor that remains the same throughout the experiment in an effort to reduce the chance of this factor influencing the DV. To identify variables you need to control in your investigation, consider other factors that might cause your DV to change. For example, when testing the effect of activity level (IV) on occurrence of heart disease (DV), you would want to make sure that each participant was of a similar age. If this factor wasn't constant, it would be an **uncontrolled variable** that could potentially affect the results, making the experiment inaccurate and invalid (Figure 2).

dependent variable (DV) the factor/s measured in the experiment that are changed when the IV is manipulated

independent variable (IV) the factor/s that is/are manipulated in an experiment

controlled variable a factor that is kept constant throughout the experiment. Also known as a **constant variable**

uncontrolled variable a factor that is not kept constant or accounted for throughout the experiment. Also known as an **extraneous variable**

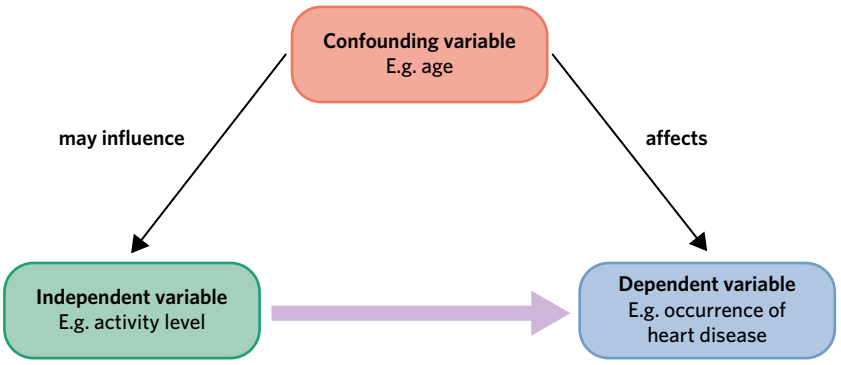


Figure 2 In this experiment, scientists are interested in determining if activity levels directly impact a person's likelihood of developing heart disease. Age is another variable in this experiment since it could influence a person's activity level and a person's likelihood of developing heart disease (older people are more likely to develop heart disease). If it is not controlled for (by only including people of a similar age in the experiment) it will serve as an uncontrolled variable, making it difficult to determine if exercise alone has an impact on heart disease.

Memory device

Remember the IV-DV-TV! Old TVs had antennae on top of them. When you moved the antennae, it affected what you saw on the screen. In this way, the antenna is the thing you manipulate (the IV) and the image is the thing you watch/measure (the DV).

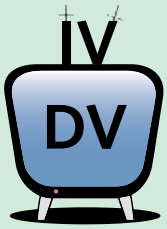


Figure 3 The IV-DV-TV

Example

HOW POWERFUL IS A POWER NAP?

Given the research question 'Do Year 11 Biology students at this school remember more if they cram or nap for one hour after a class?', use the template 'If [change in IV], then [change in DV]' to generate a hypothesis.

Note that sometimes you are also required to include an explanation that explains why you've made the prediction. In this case, your hypothesis template could be 'If [change in IV], then [change in DV] because [existing evidence]'.

_____

_____

Suggested answer
There are two IVs – napping and cramming – so we could write two hypotheses: 1) 'if students nap after learning, then they will get increased test scores'; or 2) 'if students cram after learning, then they will get increased test scores.' Or, we could write a single hypothesis that includes both IVs: 'if students nap or cram after class, then they will get increased test scores.' You could also hypothesise that the interventions do not increase test scores.

Formulate a hypothesis

From your aim, question, and variables, you can then build a hypothesis. A hypothesis is more than 'what you expect to happen' during your experiment. It should:

- be a testable statement
- describe how you think your IV will affect your DV, including the direction of change (increase/decrease etc).

Your hypothesis will either be supported or refuted by your results. A simple hypothesis format is 'If [change in IV], then [change in DV].'

Select a scientific investigation methodology

Now that you've got your research question, it's time to figure out how to actually get to the answer by conducting a scientific investigation!

Scientific investigations can be undertaken in a variety of ways depending on your research question and aim. We call these broad frameworks for inquiry the scientific investigation **methodologies**, and they help guide how you will design your specific **methods** (the actual steps in your experiment). For instance, if you want to learn what species of bacteria live on human skin, it might make sense to use a classification and identification methodology. But, if you want to understand cause and effect, you'd want to perform a controlled experiment (where you test the effect of an IV on a DV, while controlling all other variables). Controlled experiments are often difficult to set up properly, however they can provide very reliable results, and most of the KSSs you will learn in this lesson relate directly to controlled experiments. The methodologies you can use to answer research questions are outlined in Table 2.

methodology the strategy or overarching framework followed in a scientific investigation

method the steps followed in a scientific investigation

Table 2 The nine scientific methodologies prescribed by the VCAA

Methodology	Description	Example
Case study	An investigation of an event or problem that involves a real or hypothetical situation. Case studies can take many forms including historical analysis, role-play of an imagined situation, or designing a solution to a real-world problem.	Researching a bioethical dilemma such as the de-extinction of woolly mammoths, then preparing a debate or essay presenting your analysis and conclusions
Classification and identification	Classification is the arrangement of individuals or objects into logical, manageable sets. We use identification to recognise where new individuals or objects belong in these sets.	Creating a classification tree or phylogeny showing how Australian marsupials are related
Controlled experiment	An investigation into the impact of an IV on a DV, controlling for all other variables.	Testing if introducing a new gene into tomatoes protects the plants from pests
Correlational study	Observing and recording events that have not been manipulated or controlled to understand associations that exist between variables. Typically still measures the effect of an IV (or multiple IVs) on a DV, but the IV is not manipulated by the experimenter and some conditions may be less controlled than in a laboratory experiment.	Recording how environmental conditions such as day length and temperature affect timing of leaf fall in different deciduous plant species
Fieldwork	A correlational study or controlled experiment set up outside a controlled environment (e.g. the classroom), usually in a selected ecosystem. Typically still measures the effect of an IV on a DV, however, conditions may be less controlled than in a laboratory experiment.	Measuring the distribution of sea snails across the intertidal region
Literature review	The collation and analysis of other people's scientific findings or viewpoints concerning a particular topic. Consideration of the reliability of sources and methods is important in literature reviews. They are used to provide background information on a topic of interest and/or identify potential areas of research.	A report summarising past research about Indigenous Australian agriculture and aquaculture
Modelling	The construction of a model or representation that approximates an object or event. This could be a drawing, a 3D structure, an equation, a moving structure, etc., and can be used to describe systems or make predictions.	A flow chart showing the biochemical reactions that take place during photosynthesis
Product, process, or system development	Design of an object, process, or system to meet a human need.	Designing a pot that delivers different water levels to indoor plants depending on the plants' needs
Simulation	The process of using a model to observe and predict what may happen in a real or theoretical system.	Using masking tape to make a large-scale map of the body's osmoregulatory system in your classroom, then have students act out what happens to different hormone levels in different conditions

Example

HOW POWERFUL IS A POWER NAP?

There are a couple of methodologies we could use to figure out if cramming or napping improves memory:

- a case study of exemplary students, where we survey and record what those students did over Years 11 and 12
- a literature review of studies that investigate what helps students perform well in high school.

However, these investigations may provide weaker evidence than a controlled experiment:

- case studies only look at a very small group of people, and the information we get from it might not be accurate (former students might, for example, overreport the amount of napping they did)
- a literature review may not include studies specific to the region or subject we're interested in, so the results may not be relevant.

Given that we are interested in a cause-effect relationship and have identified a DV, an IV, and several variables to keep constant, we can design a controlled experiment that gives us reliable and meaningful results.

Design a repeatable, reproducible, and valid investigation

For controlled experiments, there are some broad rules around what needs to be included in your experimental design. These rules also help ensure that your experiment is:

- **repeatable** – you can repeat your experiment and get the same results over and over again
- **reproducible** – other scientists could follow your method and get the same results over and over again
- **valid** – your experiment actually measures what it claims to be measuring.

If your experiment is not repeatable, reproducible, or valid, then the results are typically not going to be useful, reliable, or meaningful. To ensure you can trust your results, you need to design a strong method. Here are some tips for ensuring your methods are repeatable, reproducible, and valid:

repeatable an experiment/measurement in which scientists, using the methods they designed, can obtain the same result multiple times

reproducible an experiment/measurement in which a group of scientists, using methods designed by others, can obtain the same results as another group's experiment

valid a measurement or experiment that actually tests what it claims to be testing

Identify your experimental group/s and control group/s

The **experimental group** has individuals exposed to your IV treatment or intervention. There may be different levels of your experimental group. For instance, if you are testing the effect of a new pesticide on crop yield, your experimental groups could be three groups of crops exposed to either low, medium, or high levels of pesticide.

experimental group a group of individuals/samples in which the independent variable is manipulated. Also known as the **treatment group**

Control groups are used as a comparison with experimental groups and every controlled experiment should include at least one control group. Control groups can be samples that are not exposed to any level of the IV, which means we do not expect it to produce any results. These are known as negative controls. Alternatively, controls can be groups where you would expect to see a result. Scientists apply a treatment to this group which induces a well-understood effect on the DV which can be compared against the effects of other IVs. These are known as positive controls.

control group a group of individuals/samples that are not exposed to the independent variable. Also known as an **experimental control**, **control treatment**, or **the control**

Negative controls are the most common and should be present in all controlled experiments. If they do produce results, we know that something other than the IV (an uncontrolled variable) may be causing the change in the DV and our method is flawed. In our pesticide and crop yield experiment, a negative control group would be a field not exposed to the pesticide at all, while a positive control group would be a field exposed to an already-existing pesticide that is known to be effective at protecting crops from pests.

Examiners' tip

Be careful not to mix up control groups and control variables. Controlled variables are factors that must be kept constant during your experiment whereas a control group is a sample that is not exposed to the independent variable.

Theory in context

MIND OVER MATTER

Placebo groups are often used as a type of control group, especially when testing medicines. Placebos are medicines/procedures that seem identical to the treatment medicine/procedure, but have no active ingredients and do not result in therapeutic benefit. This means that the participants do not know if they are part of the treatment group or the placebo group. So, if a treatment involves giving participants a pill, the placebo group would be given a pill that looks like the drug, but has no active ingredients (e.g. a sugar pill). A standard negative control, meanwhile, would just be a group of participants who receive no pill (so they know they aren't receiving treatment).

In such studies, we often note an improvement in patients treated with the placebo. This improvement is known as the 'placebo effect' and is due to the psychological beliefs of the person (i.e. if you believe you are going to get better, you will probably get better). Scientists have even figured out how to boost the placebo effect to make a medicine more effective. For example, they've learned that antidepressant pills that are yellow are more effective than the same pill of a different colour.

placebo a substance that has no active ingredients or side effects

Table 3 Examples of research questions alongside potential experimental and control groups

Research question	Experimental group	Control groups
Does the drug we have developed kill bacteria?	Bacteria in a Petri dish exposed to the drug	Bacteria in a Petri dish not exposed to the drug
Are humans injected with our newly developed vaccine protected from the influenza virus?	Humans injected with the vaccine	Humans injected with a vaccine that is already widely used to provide immunity against influenza
Does gene X make banana plants produce more fruit?	Banana plants with gene X	Banana plants without gene X

Example

HOW POWERFUL IS A POWER NAP?

What would the experimental group/s and control group/s be for our experiment on cramming and napping?

Well, we obviously need to get one group to nap after learning, and one group to cram after learning:

- Experimental group #1 – cramming
- Experimental group #2 – napping

We also need a control group, where the treatments of cramming and napping are not applied, but everything else remains constant. Perhaps the best control group would involve participants 'taking a break' at the same time as the experimental groups experience the cramming or napping intervention. It would be important that the control participants are awake and do not revise during this time.

- Control group – awake break

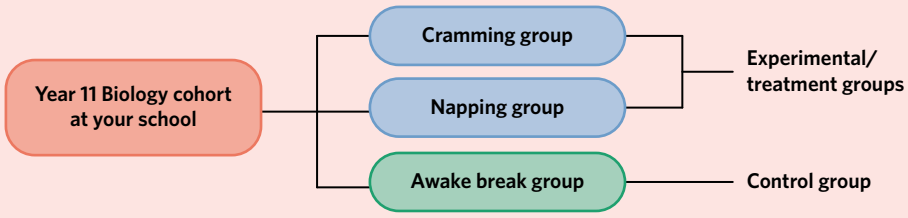


Figure 4 Diagram showing how the Year 11 Biology cohort is divided into experimental and control groups

Is the 'awake break' group an example of a negative or positive control group? What will the results from this group tell us?

_____

_____

Suggested answer
This is a negative control group, unexposed to any treatment so that we can compare the results of this group to the experimental groups. Having a negative control group will tell us if applying the intervention alters student memory of the lesson.

When you are thinking about your experimental and control groups, you also need to think practically about how each will be treated. This means asking questions like:

- what tools will I use to take measurements of each group?
- how often will I take measurements of each group?
- how long will the experiment run for?

Example

HOW POWERFUL IS A POWER NAP?

Let's make sure we know the details of how we're going to treat each of the groups over the course of the experiment.

- What tools will I use to take measurements?

We need to test if students have remembered what they learned in the class prior to the intervention (or awake break). This can be measured using a 30-minute test on the material covered.

- How often will I take measurements?

Given that memory can be both short-term and long-term, it would be prudent to test students immediately after the intervention, but also one week later. Therefore, we'll give them two tests – Test 1, immediately post-intervention, and Test 2, one week later. The tests will cover the same content but have different questions. As we need enough questions for 2 × 30-minute tests, the pre-intervention lesson should be quite long – perhaps 2 hours.

- How long will the experiment run for?

In total, the experiment will run for one week. Learning and Test 1 will take place on day 1, and Test 2 will take place on day 8.

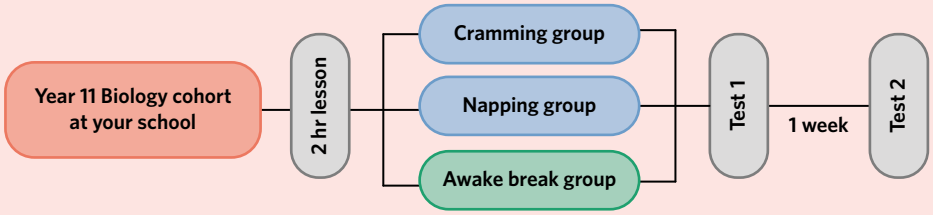


Figure 5 The design of the napping and cramming experiment

Replicate your experimental and control groups

Replication involves having multiple experimental and control groups. Using our crop and pesticide example, instead of having four different fields exposed to either no pesticide, low, medium, or high levels of pesticide, a replicated experiment would ensure there were two or more fields exposed to each treatment.

replication the process of running your test/experiment multiple times

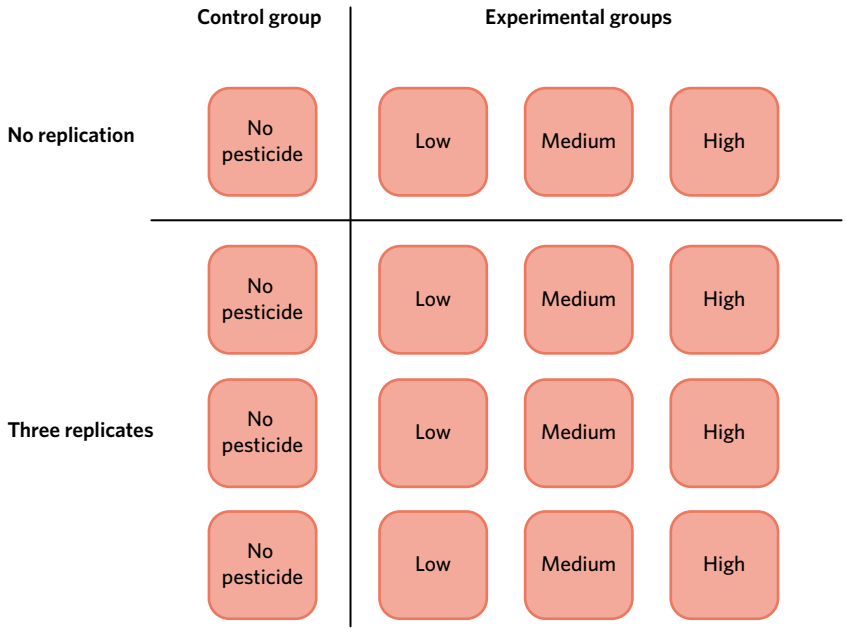


Figure 6 An example of replicated and unreplicated experimental designs testing the effect of pesticides on crop yield

Increasing replication is good scientific practice because:

- You can find out if your results are **precise**
  - Precise results indicate that your method is valid and reliable, and that you may be able to assume the same results would be found in a larger sample
  - If you get a wide spread of values across **replicates**, then results are imprecise
  - If replicates get similar results, your results are precise.
- You can take the average of your results
  - This reduces the impact of **outliers** and **random error**
  - This might make your results more **accurate**, as it may bring your final values closer to the **true value**.

Sometimes there is not enough funding, time, or resources to replicate an experiment many times. Nevertheless, you must design treatment groups with at least two replicates if you want to be able to trust your results. Depending on the field of Biology, it may be standard practice to replicate treatments hundreds or even thousands of times.

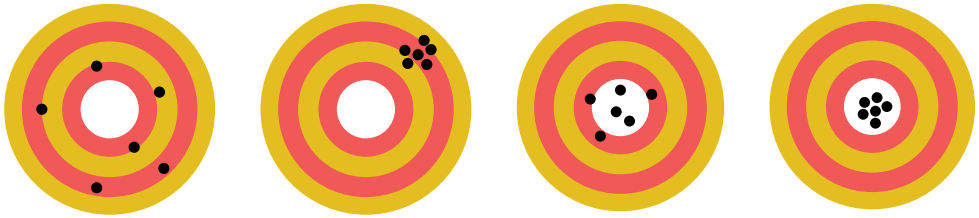


Figure 7 Accurate results are close to the true value, whereas precise results have very little spread around the mean value.

precise two or more measurements that closely align with each other

replicates multiple measurements that are exposed to the same level of the IV, are very close in value, and are close to the 'true' value of the quantity being measured

outlier a reading that varies drastically from other results

random error variation in results caused by uncontrollable conditions between replicates, resulting in a less precise spread of readings. Can be reduced using more replicates or refining the measurement process

accurate how close a measurement is to the true value

true value the value that would be obtained by a perfect measurement without the influence of errors

Examiners' tip

It is important to note, however, that calculating the average of your results after replicating the experiment only brings your final values closer to the true value if the range of your data (maximum value-minimum value) isn't too large. In other words, if your data has a large range and you calculate the average, your final results will actually be further away from the true value.

Example

HOW POWERFUL IS A POWER NAP?

To replicate our sleep study, we need to make sure that there is more than one person in each of the experimental and control groups. Ideally, we also have equal numbers of people in each group. So, if we have 90 Year 11 VCE Biology students participating in the study, there would be 30 students in experimental group #1, 30 students in experimental group #2, and 30 students in the control group. This means that the experiment has 30 replicates.

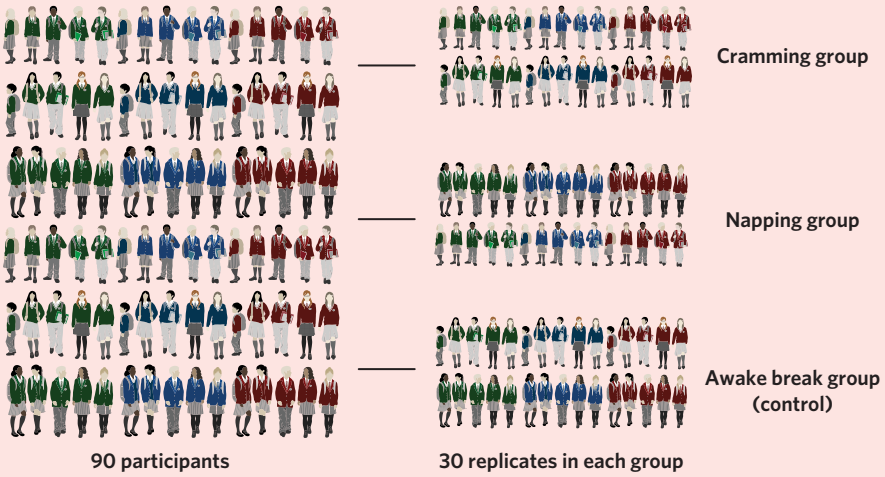


Image: Katrine Glazkova/Shutterstock.com

Figure 8 Diagram showing that there are 30 replicates in each group.

Decide how to sample your groups

It is hard to take measurements of every single individual in a **population**, so scientists tend to collect data on only a small subset of that population called a **sample**. However, because sampling only looks at a subset of a population, scientists need to be careful that their samples are:

- **representative** – accurately reflects the characteristics of the entire population
- **unbiased** – unaffected by prejudice or an inclination towards finding a specific result.

It is a good idea to get as large a sample size as possible, as this will increase the likelihood that you have collected representative and unbiased data. A larger sample size also means that you will have a better understanding of the precision of your data and can take averages to reach a final value that should be more accurate than if you only took a smaller sample. To help ensure samples are representative and unbiased, scientists can use sampling techniques like those outlined in Table 4.

population a set of similar objects or individuals that are studied in a scientific investigation

sample a subset of the larger population being studied

representative a sample that accurately reflects the characteristics of the larger population

unbiased a sample or measurement that is unaffected by a scientist's expectations

Table 4 Different sampling techniques

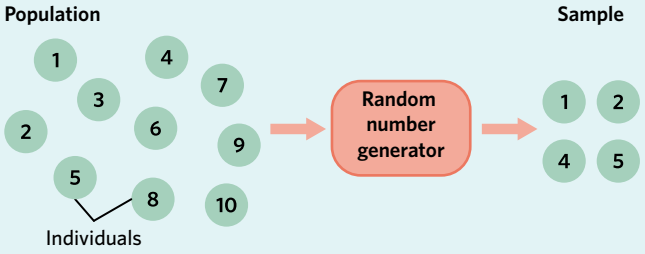
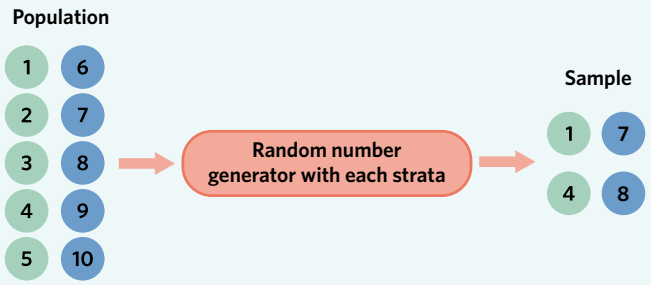
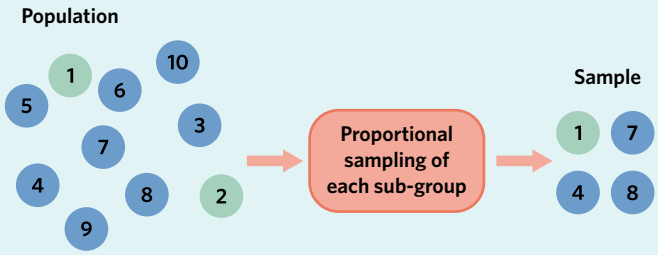
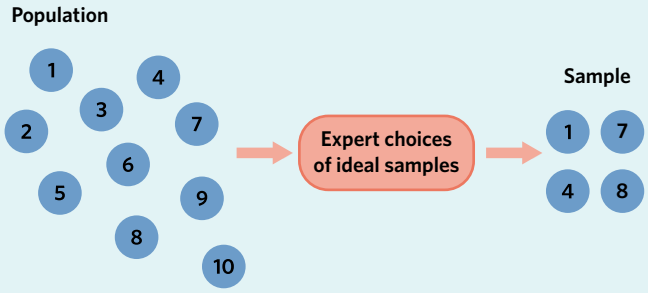
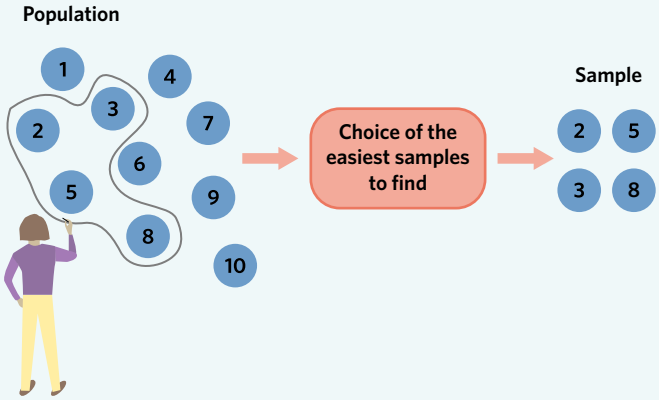
Sampling technique	Definition
Random sampling	Random sampling ensures each member of the population is equally likely to be included. 
Systematic sampling	Systematic sampling involves taking samples at regular intervals along an environmental gradient (such as depth, soil type, rainfall, altitude, or temperature). 
Stratified sampling	When a population has clearly defined zones or characteristics, and you wish to sample proportionately from each zone, you may wish to use stratified sampling.  *cont'd*

Table 4 Continued

Sampling technique	Definition
Judgement sampling	Also known as selective sampling, the researcher chooses which individuals (or asks an expert's advice) to sample according to their needs. Judgement sampling can be biased and lead to unrepresentative data, so should only be used when necessary. 
Convenience sampling	This type of sample is taken from a group of individuals who are easy to reach. Convenience sampling can lead to biased and unrepresentative samples that make results unreliable, so should be avoided where possible. 

Example

HOW POWERFUL IS A POWER NAP?

Sampling technique

In this experiment, the 90 Year 11 VCE Biology students (we can say n = 90 to explain that the sample size is 90) at your school are a sample of all Year 11 VCE Biology students that exist. We chose these students using convenience sampling – they are the students who we know and are easily available to participate.

To strengthen the experiment, we can ensure that the sample of 90 students are randomly allocated into the experimental and control groups. For example, we could assign each student a number from 1–90, then use a random number generator to determine which intervention they receive: the first 30 cram (n = 30), the next 30 nap, and so on. This is important as it minimises the risk of all 'high-achieving' students being accidentally placed into the same group, which would make that treatment appear really successful.

Of course, there is a strong possibility that students at our sample school are not representative of VCE Biology students in general. For example, your school may be more linguistically diverse than the average Victorian school. You'll need to decide how this affects your results in your discussion.

cont'd

Example

HOW POWERFUL IS A POWER NAP? –CONTINUED

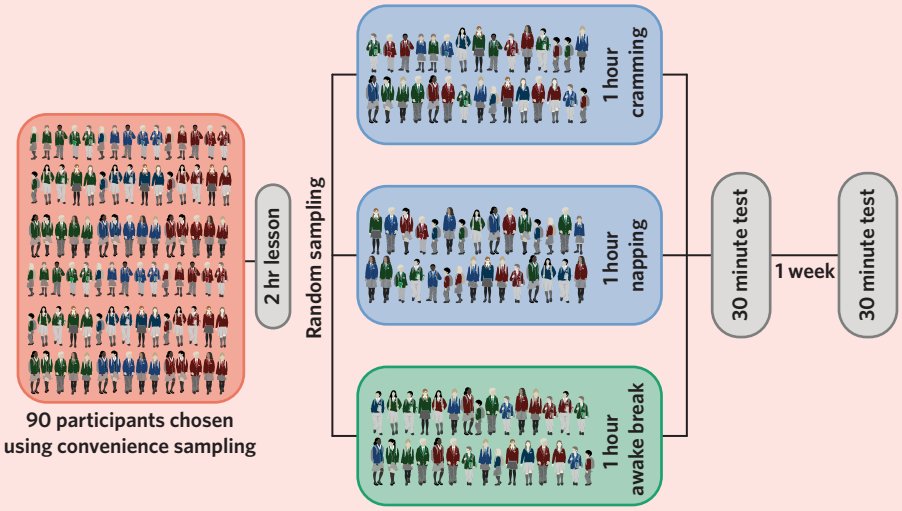


Image: Katrine Glazkova/Shutterstock.com

Figure 9 Experimental design to measure if cramming or napping improves student memory

Can you think of any other reasons why your school may not be representative of VCE Biology students?

_____

_____

Suggested answer
The postcode a school is in, access to resources, the diversity of its culture, the influence of teachers and parents, and many other factors may mean that the sample school is far from 'average'.

Minimise the potential for error throughout the method

There are three main types of errors that you should plan to avoid during your experiment, outlined in Table 5. When you are designing your method, you should make sure you choose appropriate equipment to use for measurement, calibrate equipment where needed, and build in a sufficient number of replicates to minimise error. It is also important to identify parts of the method where errors may occur (e.g. during delicate or complex processes), then either find ways to reduce the risk of error or practice the process prior to conducting the experiment.

Table 5 The error types you need to know for VCE Biology

Error type	Description	How to avoid
Personal	Mistakes or miscalculations made by the experimenter. Counting incorrectly, rounding to the wrong decimal place, or labelling samples incorrectly are all examples of personal errors.	Repeat the experiment again. For measurements relying on human accuracy (e.g. counting plant numbers), you can get two or three people to make the same measurement.
Systematic	Errors which cause results to differ from the true value by a consistent amount each time, typically due to faulty equipment or calibration. They affect the accuracy of the experiment, and cannot be minimised through replication.	Re-calibrate your instruments, or use more reliable equipment.
Random	Errors which are caused by unpredictable variations in the measurement process and result in a spread of readings. For example, when a quantity is estimated by reading between the lines on a measuring cylinder – is it 5.6 mL or 5.7 mL? Perhaps we'll just say 5.65 mL. Random errors reduce precision.	Replicate the experiment, increase the sample size, refine the measurement process, or use more precise measuring equipment.

Theory in context

QUANTIFYING UNCERTAINTY

Some instruments are more precise than others. For instance, the screen height of an iPhone X could be 14.9 cm (ruler), 14.86 cm (vernier calipers), or 14.859 cm (micrometre screw gauge). Clearly, there is more **uncertainty** associated with the ruler measurement than with the micrometre screw gauge measurement. You may wish to quantify the uncertainty associated with measuring instruments in your methods. Digital devices like scales typically state the uncertainty on a sticker somewhere. For analogue instruments like rulers and measuring cylinders, uncertainty is a bit trickier.

If you have to set up the instrument before measuring (e.g. with a ruler, you need to put it in place before measuring), then the uncertainty is the smallest measurement. On the ruler shown in Figure 10, the uncertainty is ± 1 mm. However, when you don't need to set the instrument up before measuring (e.g. a measuring cylinder, or a thermometer), then the uncertainty is half of the smallest measurement. In the measuring cylinder shown in Figure 11 the smallest measurement is 1 mL, so the uncertainty is ± 0.5 mL. Note that the uncertainty assigned to standard digital stopwatches is ± 0.1 of a second due to human reaction time.

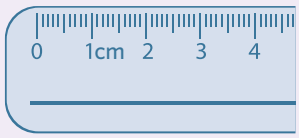


Figure 10 A section of a ruler that has an uncertainty of ± 1 mm

Image: oFFsoRRy/Shutterstock.com

Figure 11 A measuring cylinder that has an uncertainty of ± 0.5 mL

personal error mistakes or miscalculations due to human fault. Can be eliminated by performing the experiment again correctly

systematic error errors which cause results to differ by a consistent amount each time, typically due to faulty equipment or calibration, resulting in a less accurate result. Can be reduced by calibrating and maintaining instruments

uncertainty a quantification of the error associated with a measurement, often represented by the symbol '±' after a reading

Write your method out clearly

Once you know your treatment groups, replication number, sampling method, and have identified any methodological stages which may introduce error, you should write the steps of your experiment out clearly. Remember that anyone should be able to follow your method exactly – other scientists won't be able to reproduce your results if they can't follow your method.

Follow ethical and safety guidelines

Before starting your experiment, you need to ensure that your method is **ethical**. Ethical conduct is valued so highly in modern day science that, at universities and research facilities, experimental procedures must be presented to an ethics board before being permitted to proceed.

To check if your experiment is ethically sound before starting, you should ask yourself the following questions:

- Is my method designed to avoid harming living things or ecosystems as much as possible?
- Has this research considered the beliefs, perceptions, customs, and cultural heritage of those involved in, or affected by, the experiment?
- Are all participants aware of the risks associated with this research and have they provided their consent?
- If I make a great discovery, will there be equal access to, and fair distribution of, any benefits that have arisen from this research?

Memory device

You can think of the characteristics of a good controlled experiment as a checklist (RICHES):

- Replication
- Independent variable/ dependent variable
- Control group
- Hypothesis
- Errors are minimised
- Sample is large and randomly collected.

ethics a field of knowledge that helps individuals exercise moral judgment and determine what is right and wrong

- Will I acknowledge all sources of funding and help for this research?
- Will I be transparent about any errors with the data or methods?
- Is the identity of participants protected?

If you answered 'No' to any of these questions, your experiment may not be ethical and you may need to revise your method. You will learn more about ethical decision making in lesson 1B.

Example

HOW POWERFUL IS A POWER NAP?

There may be some ethical issues with our experiment on napping and cramming. For example:

- Have participants provided fully informed consent to be a part of the experiment?
- As the test is being undertaken on minors, do we need to get consent from their parents as well?
- Are there language, gender, or cultural differences that may influence student experience of the experiment?

Can you think of any other ethical questions to consider for this investigation? List them below.

_____

_____

It's important to have reasonable answers to these questions, and others, before starting the experiment.

Suggested answer

- If we use a test to measure student memory, will the score on their test affect their school results?
- Is there a safe place for students to nap?
- Will we share the results with the participants?
- Will participating in the experiment cause undue stress or anxiety for students?
- Do any of the students have a pre-existing sleep condition which means that they should avoid napping during the day?
- Can students leave the study if they wish?

Comply with safety guidelines

It is likely that, during Year 11 and 12, your teacher will ask you to take ownership of your own safety during an experiment by doing a risk assessment. This involves writing down all potential risks in an experiment, keeping in mind any contextual factors that may affect the safety of the experiment, and identifying ways to minimise these risks (Table 6).

Table 6 Examples of potential risks, contextual factors, and risk minimisation strategies during scientific investigations

Aspect of risk assessment	Examples
Possible risks	• Sharp objects • Flammable material • Hazardous chemicals • Open flames • Culturing of microorganisms
Contextual factors	• The experience of staff and students with the procedure • The behaviour of the class • Allergies of students and staff • Facilities available
Strategies to minimise risk	• Wearing personal protective equipment like gloves, lab coats, and enclosed footwear • Using fume hoods and other safety equipment where needed • Tying back long hair • Following instructions from the teacher and lab technicians • Washing hands after lab work • Keeping lab benches and equipment **sterile** • Conducting experiments in isolation • Conducting experiments in negative pressure rooms

sterile surgically clean and free from contamination by microorganisms. Also known as **aseptic**

You can undertake a risk assessment online (e.g. riskassess.com.au) or use a printed template provided by your school. The online risk assessments are helpful because they typically outline standard handling procedures for all equipment and safety data sheets for chemicals.

Example

HOW POWERFUL IS A POWER NAP?

Identify one possible risk that would need to be in this experiment's risk assessment.

_____

_____

Suggested answer
Acceptable responses include: stress from having to cram, stress from having to sit tests, stress from using up valuable VCE study time, and stress from potential disruptions to the sleep cycle.

Conducting investigations 0.0.0.12

OVERVIEW

During your investigation, you should focus on collecting unbiased, accurate, and precise raw data. In addition, you need to work cooperatively with classmates, teachers, and lab technicians to achieve the most reliable results.

THEORY DETAILS

Specific, answerable research question? Check. Appropriate research methodology? Check. Now it's time to start getting some data to actually answer your question!

Generate and collate data

If you're collecting your own data, we say you're collecting **primary data**. As you write results down in your logbook, the data is considered **raw**. Once you start graphing it or presenting it in tables, we describe that data as **transformed**. If you're getting results from someone else (e.g. a previous class, online data banks, or scientific papers) we say you're collecting **secondary data**.

When collecting primary data, it's important that you note down any observations from the experiment. In particular, write down any potential errors that may have occurred while conducting the experiment. Some examples of observations to collect during the experiment include:

- potential moments of contamination
- any personal errors, including spills or breakages
- general observations such as scents or colour changes
- any inconsistent treatment of experiment and control groups
- potential uncontrolled variables that may be affecting results.

primary data results collected from experiments, interviews, or surveys undertaken by the researcher

raw data results that have not been processed, manipulated, or formatted for use

transformed data results that have been converted from their raw format into a more visually comprehensible format that is easier to analyse

secondary data results from sources other than the researcher's own investigations

Example

HOW POWERFUL IS A POWER NAP?

Here is an example of the raw data we collected for our cramming and napping memory experiment. Notice that we have:

- tried to keep it neat and organised by using a computer rather than handwriting
- used clear headings so that anyone can interpret the data
- included a column for observations so that we can track any potential uncontrolled factors.

Student #	Group	Test 1 score	Test 2 score	Observations
1	Cram	90	88	
2	Nap	80	82	Loud noise may have disturbed nap
3	Break	42	33	
4	Break	54	52	May have dozed off during break
5	Break	70	53	
6	Cram	82	84	Only read notes, did not write anything down or highlight

Figure 12 An example of what raw data might look like

Lesson link

By writing down any potential errors that occur during the experiment and then discussing them in your report, you are communicating your results with integrity – a key ethical concept discussed in ***lesson 1B***. In doing so, you are basically saying 'my results say X, which is significant because Y, but make sure you're aware that Z happened during the experiment and that could make the results a bit dodgy'. This gives readers full autonomy to draw their own conclusions with all the required knowledge at their fingertips.

Analysing and presenting results 0.0.0.13

OVERVIEW

Once you've finished conducting your experiment, you need to interpret and present your results. This typically involves transforming your data into a graph or table, determining any potential sources of error, drawing conclusions from your data, and then communicating your findings to a specific audience.

THEORY DETAILS

After your investigation, you need to start thinking about what your results mean and how to communicate them. There are four steps to follow in order to do this (Figure 13), which we'll go through in more detail below.

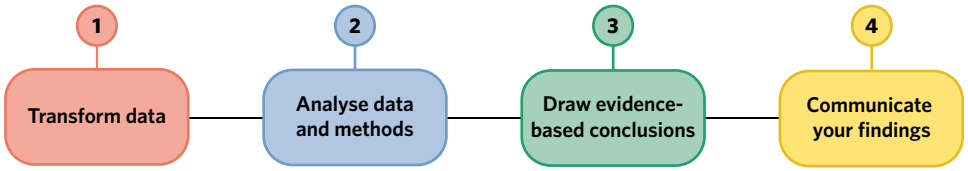


Figure 13 Steps to presenting and communicating results

1. Transform your data

A crucial part of being a scientist is communicating your results clearly and honestly. In practical reports and posters, raw data is not usually presented because it can be hard to read, repetitive, irrelevant, or messy (and, frankly, sometimes a bit boring!). Instead, data is manipulated so that the main result, pattern, or trend is obvious. Tables are not always the best way to show trends, so results sections will typically include graphs and charts.

The type of graph you choose depends on the type of data that you have collected. Table 7 outlines the different types of data you may collect, and how you can represent that type of data.

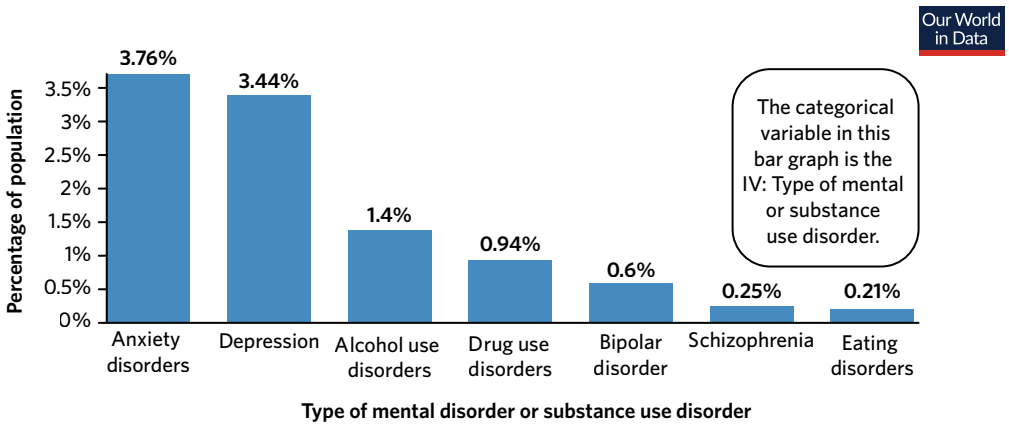
Table 7 Types of data you may collect about variables and how they are best graphed

Type of variable		Explanation	Typically graphed using
Numerical	Continuous	Data that can take any value between a set of real numbers. In other words, continuous data can include decimals and fractions e.g. height (178.87 cm), age (16 years 2 months 4 days...), mass (65.87 kg)	Line graph or scatter plot
	Discrete	Data that can be counted and takes a particular value. Discrete data cannot take a fraction of that value e.g. count of individuals (1, 2, 3)	Bar graph
Categorical	Ordinal	Data that can be logically ordered e.g. size (small, medium, large), fin health score (1 = no fin damage, 2 = some fin damage, 3 = most of fin surface damaged), attitudes (agree, neutral, disagree)	Bar graph or pie chart
	Nominal	Data that cannot be organised in a logical sequence, e.g. gender (male, female, nonbinary, other), nationality (Australian, Chinese, South African, Egyptian), hair colour (brown, black, blonde, red)	

numerical variable a factor that is measured as a number such as height, count of population, and age

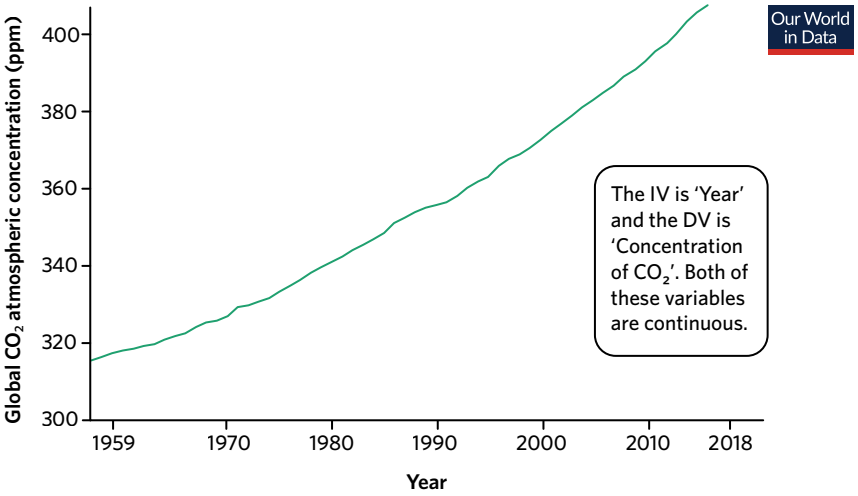
categorical variable a factor that is qualitative, typically describing a characteristic such as gender, birth order (1st, 2nd, 3rd), or nationality

Bar graphs (Figure 14) are typically used to display categorical and discrete data, whereas line graphs (Figure 15) and scatter plots (Figure 16) display continuous data. Scatter plots are particularly useful if you wish to visualise the relationship between two continuous variables (e.g. amount of rainfall and number of species in an ecosystem). If one variable is categorical but the other is continuous numerical, bar graphs usually work well. Note that, typically, the IV is presented on the x-axis and the DV is presented on the y-axis.



Source: Global Burden of Disease Collaborative Network (2017) adapted by Ritchie and Roser (2019)

Figure 14 Bar graph showing the prevalence of mental disorders and substance use disorders in 2017



Source: Keeling (1974) and the National Oceanic and Atmospheric Administration (2018) adapted by Ritchie and Roser (2019)

Figure 15 Line graph showing the change in global carbon dioxide atmospheric concentration over the past 60 years

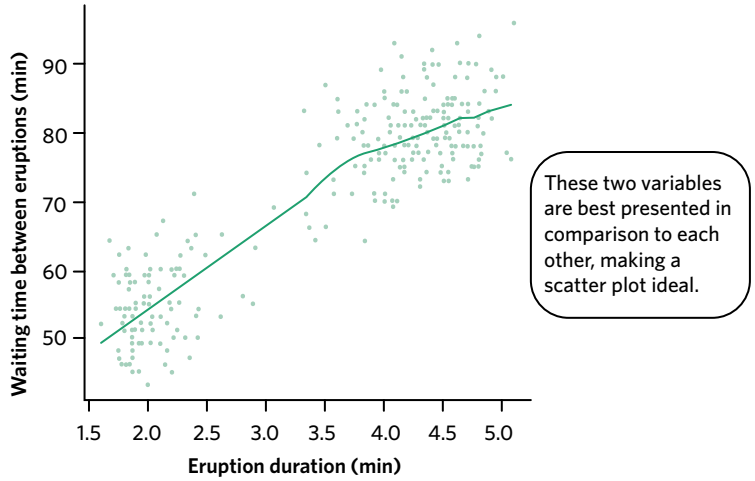


Figure 16 Scatter plot showing that the longer the wait time between eruptions of the geyser Old Faithful, the longer the duration of the next eruption.

During experiments, you may record continuous data enabling you to create a scatter plot. For example, you may record the oxygen concentration in a sealed jar with a plant inside every five minutes. Because both variables are continuous you can make the scatter plot a line graph by drawing a **trendline** also known as a line of best fit. The trendline will help readers determine if the relationship between the two variables is positive, negative, or non-existent. A line of best fit may pass through all the points, some of the points, or none of the points (Figure 17). A good rule of thumb when drawing a line of best fit is to ensure the number of points above and below the line are equal.

trendline a line that shows the main pattern followed by a set of points on a graph. Also known as a **line of best fit**

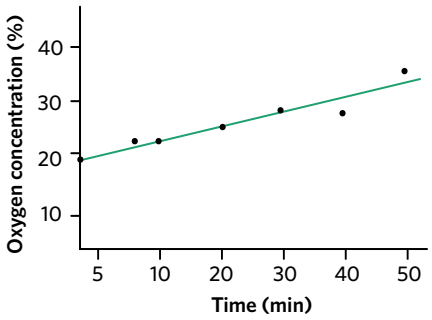


Figure 17 The line of best fit showing the general trend between two variables on a scatter plot

Once you've drawn up your graph on paper or on the computer, you need to format it to maximise clarity and to ensure it fits scientific conventions. Some guidelines for formatting are:

- ensure the graphics are clear and easy to read
- the scale should be appropriate for the data, and labelled clearly
- ensure the graphs do not have coloured backgrounds or grid lines, unless required to present results clearly
- axis labels should be formatted in sentence case (Not in Title Case and NOT ALL CAPS). Only the first letter of the first word should be capitalised, as well as any proper nouns
- any calculations should be presented in a clear, non-repetitive manner (e.g. by using one sample calculation)
- each graph should have a figure number and caption underneath
- each table should have a table number and title above
- tables should have units written in the column or row headings only, and not in the cells within the table
- the results section also includes text. The text should summarise the key findings for each graph in 1–2 sentences, including if the result supports the hypothesis.

Example

HOW POWERFUL IS A POWER NAP?

In our experiment, the DV was memory, as measured by a score on a test. The IV was study technique – cramming or napping. Classify the DV and IV as categorical or numerical, and continuous, discrete, ordinal, or nominal.

Suggested answer
Score on test = numerical, discrete (because you either get the mark or don't get the mark)
Study technique = categorical, nominal

Example

HOW POWERFUL IS A POWER NAP?

There are so many ways to present the data on test scores. Here, we'll walk through how you could transform the data you collect on study technique and memory.

If you turn our raw data point (Figure 12) into a graph, you'll see what score each student received in each week (Figure 18).

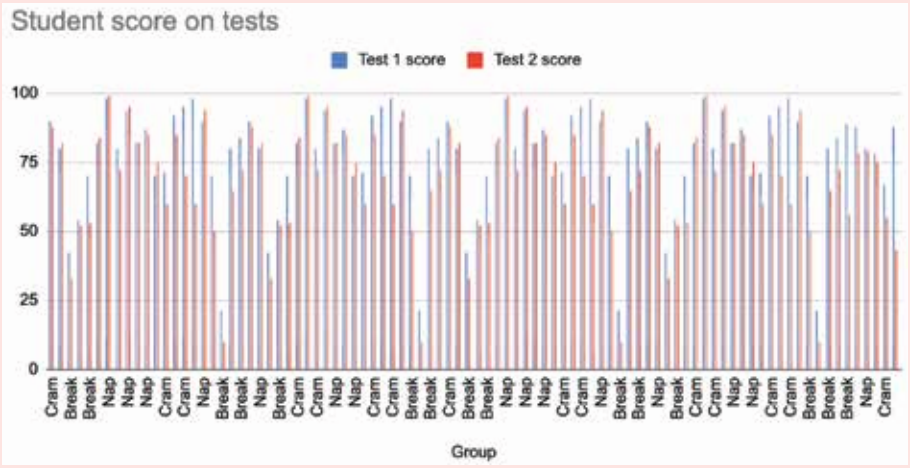


Figure 18 Raw data represented on a bar graph

Figure 18 is easier to read than a table, but is still a little confusing: you can see that the students performed differently, but you can't see if there is a difference between groups that used different study techniques. In essence, the graph is not telling a story yet. Ultimately, we want our graph to clearly answer our research question 'Do Year 11 Biology students at this school remember more if they cram or nap for one hour after a class?'. To do this, we need to figure out the mean score each group achieved on the tests. You can calculate this by summing up all the test scores within a group, then dividing that number by 30 (the number of participants).

Group	Test 1 mean score	Test 2 mean score
Break	62.03	49.13
Nap	85.40	86.73
Cram	86.23	72.47

Figure 19 The mean test scores for the students who breaked, napped, and crammed after learning.

We can then use the means to create a graph that shows our results clearly. Look at the graphs in Figure 20. Which do you think is most appropriate for representing our data, (a) or (b)? Why?

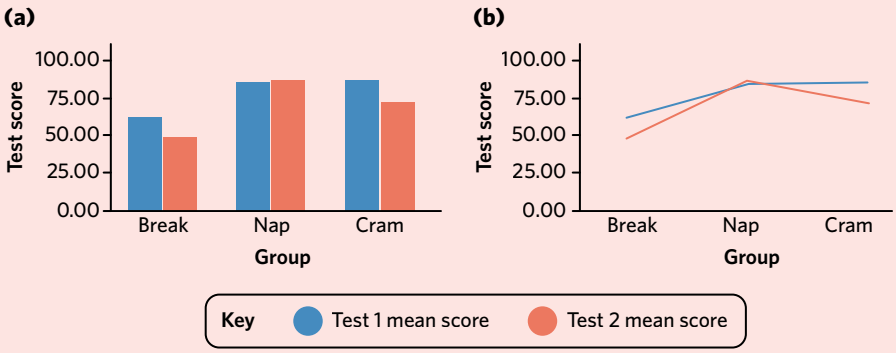


Figure 20 **(a)** A bar graph showing the average score on tests 1 and 2 using different study techniques and **(b)** a line graph showing the average score on tests 1 and 2 using different study techniques

Suggested answer
Graph A represents the data best because neither the IV nor the DV is continuous. In particular, using a line graph for (b) implies that there are values between 'Break', 'Nap', and 'Cram' (e.g. half break-half nap), which is not the nature of these nominal variables.

2. Analyse your data and method

Once you visualise your results clearly, you can:

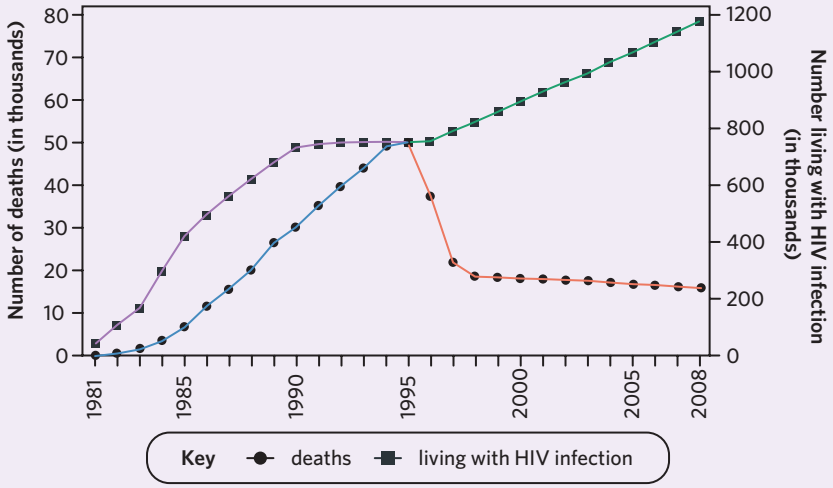
- determine if your hypothesis is supported or rejected
- reflect on your data and method to decide if your experiment is valid and reliable.

It is usually pretty easy to tell if the data support your initial hypothesis – you simply check if the data follow the pattern you expect, or if it does not. Often, you may find that the hypothesis is partially supported by your results. This is always really interesting, as your next step is to think of reasons why the pattern was not consistent. It may be due to an error in your method, or due to an unknown uncontrolled variable.

Theory in context

During exams, you may be asked to describe data before you explain it. A good plan of attack to describe the data is to divide the graph into different sections.

For example, in this graph from the 2018 exam, it would be difficult to describe everything that is happening all at once. But we have superimposed different colours over particular sections of the data which makes it easier to interpret the line graph in sections.



Source: adapted from NIDA (2020)

Figure 21 An exam question that requires students to interpret a line graph

Here is an example of how you could describe this data:

The number of deaths from HIV rose steadily from 1981, reaching a peak in 1995 at 50 000. This was followed by a sharp decline in deaths from 1995–1997, until plateauing around 20 000 for the next ten years. Meanwhile, the number of people living with HIV rose from close to zero to 800 000 between 1981 and 1990. This number stayed at approximately 800 000 for five years before increasing linearly to 1 200 000 by 2008.

Note that the description includes numbers from the x and y-axis to contextualise the overall pattern.

Once you know what your results mean for your hypothesis, you can then dig deeper into the data and evaluate your method. Some questions you may wish to consider include:

- Method
  - Did anything happen during the experiment that might mean you can't trust a data point, or multiple data points?
  - Identify any personal, systematic, or random errors that may affect the accuracy and precision of your results.
- Data
  - Precision – are the results within replicate treatments similar or different? If there is a wide spread of results this could mean your instruments or processes were not valid and did not measure what you wanted to measure.
  - Accuracy – if you know what the true value should be, are the values you recorded similar or different? If they are different, this could mean an uncontrolled variable was affecting your results, your instruments were faulty, or that you were not collecting data carefully enough.
  - Outliers – are there any data points that stand out or do not follow the pattern? If so, did something happen when you collected that sample that could explain the anomaly? There may be a good reason to exclude outliers from your results, but make sure you report in your discussion that you did this and why.

The answers to these questions, and any others that may be relevant, should be brought up in the discussion section of a report, article, or poster.

3. Draw evidence-based conclusions

One of the beautiful and frustrating things about science is that things that are 'true' one day can be disproven the next. Scientists draw the most reasonable conclusions based on the evidence available at the time. If evidence to the contrary arises, what is 'true' can also change. However, we cannot instantly accept this unless we can trust the results of an experiment. To trust results, the experiment must be designed to be reproducible, repeatable, and valid. These characteristics ensure that any conclusions drawn are 'evidence-based', reliable, and meaningful.

Theory in context

SHIFTING PARADIGMS IN BIOLOGY

Biological models and theories change when more evidence is gathered. For example, scientists used to assert that genes could only be passed down from parents. But in the 20th century, biologists discovered that bacteria could transfer genes horizontally between individuals, like swapping clothes. The fields of evolution and phylogenetics are still trying to include, understand, and adapt to this new understanding of genetic transmission.

The strongest evidence is derived from controlled experiments that use random sampling methods and have been reviewed and reproduced by colleagues in the scientific community. Other scientific investigations can provide evidence to draw conclusions from, but it may not be as reliable, as the methods used are typically not as reproducible, repeatable, and valid. Conclusions may also be drawn from **anecdotes** or opinions, though these are not considered reliable sources of evidence as they are subject to no or low replicability and large amounts of bias.

Drawing conclusions from evidence isn't always easy. There are two common mistakes that students make when drawing conclusions: assuming that 1) **correlation** means **causation** and 2) the same pattern will exist beyond the data you measured.

anecdote evidence involving a personal account or report of a previous experience that may provide a certain level of support for a position

correlation when there is a relationship between two variables

causation when change in one variable leads to reliable change in another

Correlation does not mean causation

Not all experiments will reveal a correlation between two variables – in fact you may find that the DV and the IV are unrelated. Furthermore, even if your data indicate that your IV is related to your DV in a consistent and measurable manner (e.g. if you increase the IV, the DV increases), this doesn't necessarily mean that the IV causes the change in DV. In other words, correlation of two variables does not mean that one causes the other.

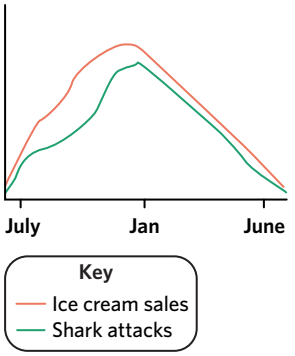


Figure 22 The number of ice cream sales and shark attacks are correlated, but one does not cause the other. It's more likely that an uncontrolled variable – for example, hot weather – explains the relationship (i.e. when it's hot, people are both more likely to eat ice cream and go to the beach, the latter likely increasing the number of shark attacks).

Data may not follow the same trend outside of the range you measure

In Figure 23, scientists measured the height of a seedling for ten days. Although a positive trend exists – indicating that seedlings get taller with time – we cannot assume that the growth will continue after day ten. Therefore, it is not correct to state that 'it will take the seedlings 20 more days to reach 9 cm'. One could, however, say that 'if the rate of growth continues in the same manner, then it will take the seedlings 20 more days to reach 9 cm'.

Similarly, the scientists did not collect data on day zero. So, when drawing a line of best fit, it is important not to force your line through zero. Drawing a trendline that is forced through zero results in a different slope (red dotted line) to the trendline that actually best fits their data (green line).

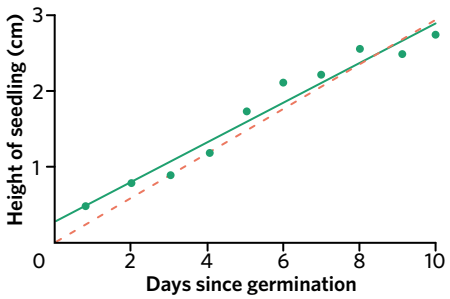


Figure 23 When drawing a trendline, avoid forcing your data through zero (red dotted line) as you end up with a different slope that doesn't accurately represent the data you collected (green).

Example

HOW POWERFUL IS A POWER NAP?

Let's see if we can draw some conclusions from our data on power napping and cramming. Here is our data:

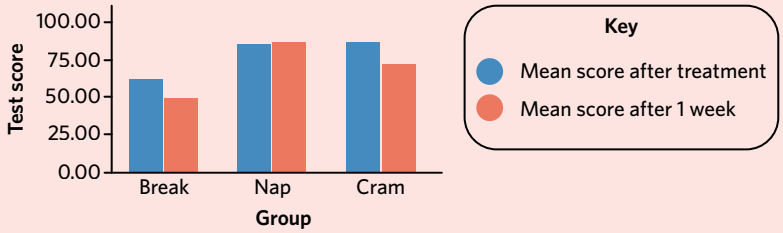


Figure 24 Transformed data showing that napping and cramming after learning improves student performance on tests more than taking a break, and that napping is better than cramming for long term memory formation

From these results, we can tell that both napping and cramming for one hour after a lesson are better study techniques than just taking a break – average students in these groups scored more than 20 points higher than control participants. After one week, students in the cramming group had forgotten more of the lesson than students in the napping group. In fact, the average test score for students in the napping group actually increased slightly. This tells us that for long term retention of knowledge, it is best to take a nap after studying. For short-term retention, you can either nap or study – both will help you achieve better scores than doing nothing.

Ok, so that's what our data tell us. Are there any reasons why this data might not be reliable? How could we address these limitations? Here are a few points that could be worth exploring:

Table 8 Limitations and potential solutions for the experiment 'how powerful is a power nap?'

Limitation	How to address
We used convenience sampling, so we can't assume the same pattern would exist in a different student population.	Collect a larger, random sample of students from lots of different schools. Or you could explain that it doesn't matter that you used convenience sampling, as you wish to determine the best study technique for you, and Biology students at your school are probably more similar to you than Biology students at a different school.
We never dictated in our methods what students should do in the week between tests – if some students studied and others didn't this would impact the results.	Ensure that all students do not study the test preparation material over the next week.
There were a number of variables that we did not control for in this investigation. For instance, did any individuals take medication, drink coffee, or have unusual sleeping routines? Were there any external life events that could have affected individual or group performance? If these variables were similar across groups, they shouldn't affect our results. But if one group is more affected than another, then our results may not be accurate.	Design a more controlled study, where participants are only included if they agree not to consume food or medicines that are stimulants or depressants. Alternatively, we could ask participants to track what they eat and how much they sleep during the study then retrospectively try to see if there are potential issues.
We haven't designed an investigation that helps us understand why napping cements learning.	To be sure that napping is the true underlying cause of improved memory, further investigations into the mechanism behind memory formation need to be undertaken.
There is a possibility that the napping group ended up with lots of high achieving students, and the awake break group was mostly composed of unmotivated students.	Ensure that the groups are composed of academically diverse students by using stratified sampling.

4. Communicate your findings

As we face global challenges like climate change, pandemics, and pollution, it is crucial that all citizens have basic scientific literacy. However, approximately forty per cent of Australians report being uninterested in, and disengaged from, science (Cormick, 2014). One of the major barriers to improving scientific literacy is that scientists often use complex, technical words and high levels of detail which can make science seem boring or difficult.

Professional science communicators emphasise that the best way to communicate your findings depends on your audience. For instance, to communicate your results to your teacher or supervisors, a formal laboratory report written according to standard scientific practice would be most appropriate. However, if you are trying to teach your siblings or parents about something you learned at school, you should avoid jargon and perhaps use drawings and examples to support your communication.

In this book, you'll find more information on specific communication techniques for assessments in Unit 4 Outcome 3 in the section called 'How to conduct a practical investigation '. In addition to these assessments, your teacher may ask you to complete practical reports on scientific investigations you conduct. To help you communicate your findings clearly, Table 9 outlines the typical conventions and formats for each section.

Lesson link

Check out the ***How to conduct a practical investigation*** guide which includes a visual example of a poster you might create for your SAC. This guide is found after Chapter 11.

Table 9 The components of a practical report, including the suggested length and tense of each section

Section	Section description	Suggested length	Suggested tense
Title	The title may be written as a question or statement that describes the main phenomenon you are trying to determine in your experiment. Examples include: • How does light intensity affect the rate of photosynthesis? • Does the theory of natural selection explain the increasing carp (*Cyprinus carpio*) population in the Murray River? • The impact of pH on the rate of enzyme-catalysed reactions • The isolation and characterisation of spermatogonial stem cells in the fat-tailed dunnart (*Sminthopsis crassicaudata*) • What does medical student study behaviour look like, and is it effective? • Bathing salmon in cold water is an effective treatment for removing skin parasites Note that if you are investigating a particular species you may wish to include the species name in the title.	One sentence	Present
Abstract	Abstracts are optional but recommended. In essence, the abstract is a short overview of the entire experiment. One formula you could use for writing an abstract is answering each of these questions in one sentence, then using linking words to make the paragraph flow: • What is the significance of the experiment? • What was the aim of the experiment? • What was your method? • What were your results? • Why are your results important? • Given these results, what should be researched next? Or, what are the broader implications of these results?	100–300 words	Past

con'd

Table 9 Continued

Section	Section description	Suggested length	Suggested tense
Introduction	The purpose of the introduction is to justify why you needed to perform your experiment. Introductions generally contain the following information (not necessarily in this order): • Background information. This may include: – Why the system or model is important to study › For example, photosynthesis is important to study as it plays a major role in controlling the levels of different gasses in our atmosphere. – The broader implications of answering your particular question – Any prior research that has been undertaken › This may include pilot studies your class undertook or research by other sources. – Any gaps in knowledge, and how your experiment could fill that gap • The aim of the experiment • The variables that are being tested • The hypothesis – As well as a justification for your prediction • The final sentence of the introduction is typically 'big picture', suggesting how what you discover could help the world or influence future research.	Variable – check with your teacher, but usually one to four paragraphs	Mostly present and future
Method	The purpose of a method is to outline all the materials and steps you took during an experiment. Like a cooking recipe, it must be very detailed so that someone else could read it and follow your steps exactly. You can usually write the method in steps and in third person, using short sentences and direct language. Make sure you: • Write the steps in order • Name any equipment used – You may wish to outline if/how the equipment was maintained or calibrated. • Draw and label any complex experimental setups • State what you measured and when	Usually no longer than half a page	Past
Results	The purpose of the results section is to present the key findings of the study in a clear and honest manner. You do not usually present raw data in the results section, but manipulate it into transformed data (e.g. table, line graph, bar graph) that best shows any trends, patterns, or relationships that exist. Each figure is accompanied by a brief (2–3 sentences) description of the key findings. If statistical analyses have been performed, they are presented here as well. Do not interpret or explain your findings in this section.	Variable – it depends on the number of figures and tables	Past
Discussion	The purpose of the discussion is to determine if the data obtained supports the hypothesis and to explore the implications of the findings. It is very important that you highlight any problems that arose during the experiment in the discussion, as well as any limitations of the data. One way you could structure a paragraph in your discussion would be to: • Restate one key result (e.g. the result from one figure) • State if the result supports or refutes the hypothesis • Discuss if your findings support or differ from prior research – Be sure to reference sources • Weigh up the strengths and weaknesses of the data to determine if the result can be trusted – Identify reasons why this result may be invalid or unreliable. Here, you could refer to: › Personal, systematic, or random errors › Precision, accuracy, and uncertainty of data › Problems with the experimental design › Other studies that contradict your data – Identify reasons why the results may be limited – what is the data not telling us that would be useful to know? – Suggest how the method could be changed to overcome any problems – Identify any strengths that support the validity, reliability, and scope of the results	At least one paragraph – usually three or four	Mostly present

cont'd

Table 9 Continued

Section	Section description	Suggested length	Suggested tense
Conclusions	The purpose of this section is to summarise your study. Generally, conclusions begin by stating whether the hypothesis was supported. They also may include: • Justification of why the hypothesis is supported/rejected • Summary of limitations and improvements • The broader implications of the results, for example – Future research – The impact on scientific knowledge – The impact on society/environment	One paragraph	A mix, but mostly present
Acknowledgements	Individuals involved in the experiment should be recognised for specific contributions.	One to three sentences (not included in word count)	Present
References	A list of references in a standard style (e.g. Harvard or APA) should be included. For more information on how to reference, please refer to the Strategies for Success lessons included in this book.	Typically anywhere from 2–20 references (not included in word count)	N/A

Example

HOW POWERFUL IS A POWER NAP?

The investigation we've been stepping you through for this lesson is not made up – there is strong evidence that suggests daytime naps improve long term memory formation more than cramming. You can read the original research here: academic.oup.com/sleep/article/42/1/zsy207/5146032

This is how we'd reference the article in the Harvard style:

Cousins, J., Wong, K., Raghunath, B., Look, C., Chee, M. (2019). The long-term memory benefits of a daytime nap compared with cramming. Sleep, 42 (1).

Theory summary

KSSs are a set of capabilities that help build scientific thinking. There are opportunities to develop, demonstrate, and test your KSSs throughout VCE Biology. Figure 25 summarises the questions you should ask to demonstrate KSSs in scientific investigations.

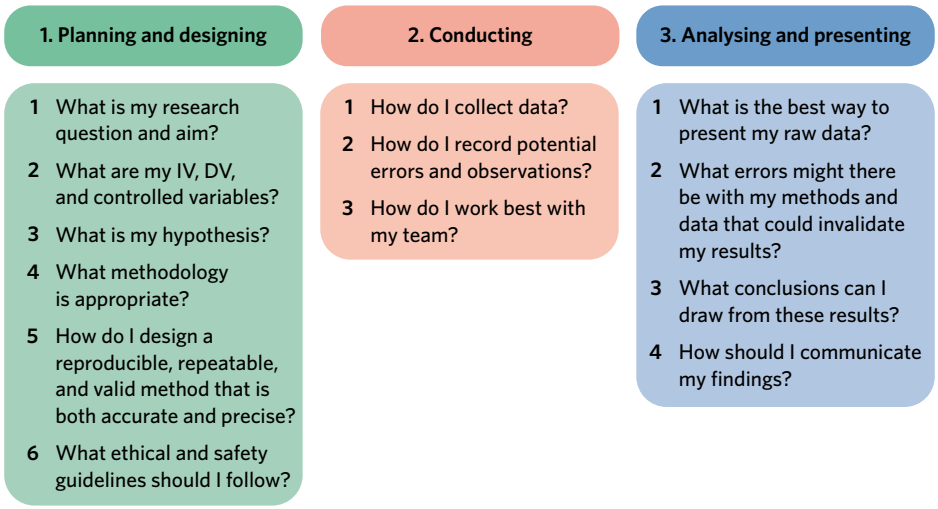


Figure 25 A summary of the questions to ask to demonstrate KSSs

The process of creating the HPV vaccine would have started with an observation about the nature of the virus – perhaps it is closely related to another virus, or it has a particular protein embedded in it's protective envelope. From there, the scientists would have constructed a research question, aim, and hypothesis about the nature of a HPV vaccine. They would have selected a methodology and developed a method for creating the vaccine, then tested it using random sampling, replication, and control and experimental groups, all the while attempting to minimise error.

To uphold ethical and safety guidelines, the vaccine would first be tested on cells and tissues, then animal subjects, and then, if it passed the previous trials, humans. The original HPV vaccine was tested on more than 20 000 females in 33 countries and 4 000 males in 18 countries before it was approved for general commercial use. Usually it takes more than 10 years to invent and approve a new drug, and only ~ 1 in 5 000 drugs that are 'invented' end up making it to market. What happens with the other 4 999? The results may not have supported the hypothesis that the drug would be effective, the method may have been unreproducible, the results may have been inaccurate or imprecise, the side effects may have made the drug unethical to sell – any number of things may have gone wrong. Luckily, rigorous testing using KSSs means that these ineffective or potentially dangerous drugs don't make it to pharmacies.

1A QUESTIONS

Theory review questions

Question 1

KSSs are

A the set of capabilities that people demonstrate when undertaking scientific investigations.

B biological theories and knowledge that must be memorised for the exam.

Question 2

An example of a testable, specific, and realistic research question is

A 'Does garlic inhibit the growth of the bacteria *Staphylococcus epidermis*?'

B 'How does garlic affect the growth of the bacteria *Staphylococcus epidermis*?'

Question 3

Which of the following options outlines all true statements about variables in experiments?

	Independent variable	Dependent variable	Controlled variable	Uncontrolled variable
A	manipulated	measured	a group in which the IV is not manipulated	a factor that might influence the results
B	measured	manipulated	kept constant	neither measured nor kept constant
C	manipulated	measured	kept constant	neither measured nor kept constant
D	measured	manipulated	measured	not measured but kept constant

Question 4

Control groups are important because they

A help us to make assumptions beyond the sample population.

B reveal if any factors besides the IV are influencing the results.

Question 5

Which of the following is true regarding replication? (*Select all that apply*)

I Replication decreases the influence of outliers on results, and proves that the same result can be achieved multiple times.

II Replication improves the reliability and validity of experiments, as it shows data are not due to random chance.

III Replication reduces the impact of random error, but cannot reduce systematic errors.

IV Replication, repeatability, and reproducibility are different words for the same thing.

V Replication always makes measurements more accurate and precise.

VI Replication never affects accuracy or precision.

Question 6

Fill in the blanks in the following sentences.

_____ errors decrease the precision of results. _____ errors decrease the accuracy of results. One way to increase _____ is to ensure all instruments are calibrated correctly. One way to increase _____ is to use appropriately sized measuring equipment.

Question 7

Which of the following is an example of a strategy to minimise risk in an experiment that involves growing plants?

A avoid using hazardous chemicals

B allergies of individuals in the class

C following Bunsen burner safety procedures

D sanitising equipment and benches after lab work

Question 8

Order the types of evidence from most to least reliable for drawing scientific conclusions.

I opinion

II anecdote

III primary data from a controlled experiment

IV primary data from an unreplicated case study

SAC skills questions

Case study analysis

Use the following information to answer Questions 9–12.

Scott and Mark Kelly are identical Caucasian male twin astronauts who participated in NASA's first ever twin study on the physical, molecular, and physiological effects of long-term space flight. Scott Kelly spent an entire year onboard the International Space Station whilst Mark Kelly remained on Earth.

Scott and Mark Kelly had both previously been on three short-medium length space expeditions (less than 300 days) prior to this study.

Both brothers had blood and urine samples taken routinely at the same time over the course of the previous months prior to Scott's departure, as well as routinely during the 12-month period Scott was in space, and for 6 months after the expedition. While living in space, Scott followed a strict diet and exercise regime like all astronauts, however, Mark did not have this restriction placed on him while living on Earth.

Question 9

Identify the control in this experiment.

A Scott Kelly

B Mark Kelly

Question 10

Which of the following is not a limitation of NASA's study design?

A The sample size is too small.

B Only Caucasian males were used in the study.

C NASA used twins which limits the genetic diversity of their samples.

D Mark and Scott Kelly had both previously been to space, and therefore may have some preexisting adaptation.

Question 11

Identify an uncontrolled variable in this study.

A timing of blood and urine tests

B location of participants

C diet of participants

Question 12

Why did tests continue to proceed six months after the expedition?

A to detect any new adaptations that arose from the expedition

B to detect how long it took to adjust back to normal conditions on Earth

Exam-style questions

Within lesson

Question 13 (1 MARK)

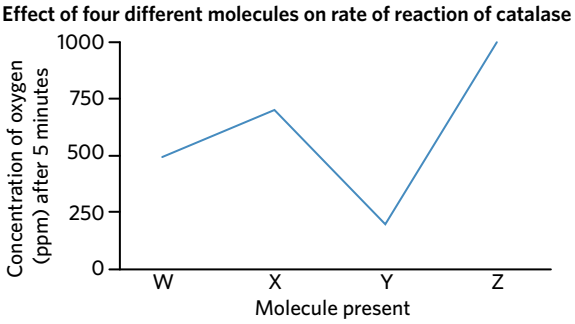
A student investigated the effect of the presence of four different molecules, W, X, Y, and Z, on the rate of reaction of catalase, an enzyme which converts hydrogen peroxide into water and oxygen. The production of oxygen was recorded over a five-minute interval. The final concentration of oxygen was recorded. The data collected is shown in the table.

Molecule present	Concentration of oxygen (ppm) after five minutes
W	500
X	700
Y	200
Z	1000

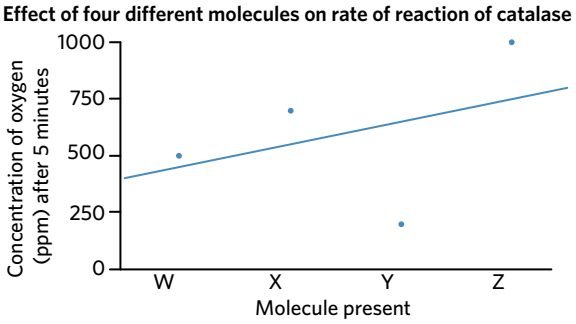
The student presented the results as a graph.

Which one of the following graphs is the best representation of the results?

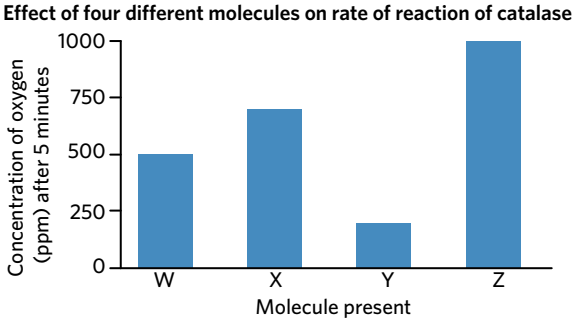
A



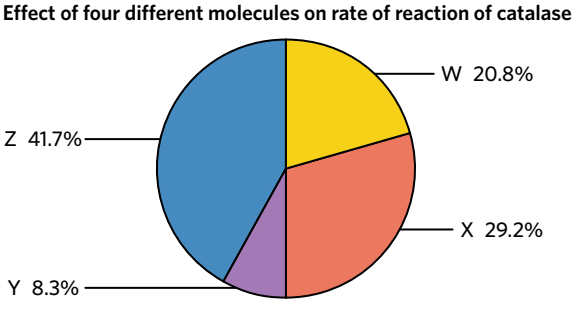
B



C



D



Adapted from VCAA 2020 Section A Q40

Question 14 (1 MARK)

Which of the following statements is correct?

A Precision is how close the measurement is to its true value.

B The true value is any measurement taken in an experiment.

C Accuracy is how closely each replicate is to other measurements.

D Validity is whether a measurement records what it is supposed to.

Adapted from VCAA 2018 Northern Hemisphere Exam Section B Q11e

Question 15 (12 MARKS)

Some plants are resistant to attack by insects because they produce a protein that poisons the larval stage of some insects that feed on them. The production of the protein is under the control of a gene found in the plant. A particular species of crop plant that does not usually produce the protein was genetically engineered to contain this gene. Such plants are referred to as genetically modified (GM) plants. These GM plants produce the insecticide protein.

Two farmers have properties next door to each other and grow the same cereal crop.

- Farmer X wishes to grow GM crops that are resistant to attack by insects.
- Farmer Y wishes to continue to grow non-GM crops.

Farmer Y was concerned that pollen from farmer X's GM crop could fertilise her non-GM plants, causing the next generation of Farmer Y's crops to produce the insect-poisoning protein.

The farmers agreed to carry out field trials to establish whether leaving a gap between crops reduced the likelihood of cross pollination. A number of trials were planted so that the results of one trial did not interfere in any way with the results of another. The percentage of seeds produced at various positions as a result of cross-pollination was measured for each trial. The outline of these trials and the results gathered are shown in the following table.

		Percentage of cross-pollination	
		at edge of non-GM crop	10 metres into non-GM crop
Trial 1 GM | non-GM	no gap between plots	10	2
Trial 2 GM non-GM	5 metres between plots	1	0.5
Trial 3 GM non-GM	7 metres between plots	1	0.3

a State the independent and dependent variables in the field trial. (1 MARK)

b Was a control group used in this experiment? Explain your response and, if a control group was not used, describe what an appropriate control group would be for this experiment. (2 MARKS)

c From the data, what conclusions can be drawn about cross-pollination and the gap between crops? (3 MARKS)

d Farmer X was dissatisfied with the results of the trial, and insisted that they undertake another trial with replication.

i Explain why this is a good suggestion. (1 MARK)

ii Draw and explain an experimental setup the farmers could use in a field trial with replication. (2 MARKS)

e In an attempt to minimise error, a number of trials were planted at different times so that the results of one trial did not interfere in any way with the results of another. Explain one potential problem with this experimental design. (2 MARKS)

f Eventually, the farmers decided to plant their crops 5 m away from each other, agreeing that this should keep the amount of cross-pollination low. After a few years, Farmer Y's initially non-GM crops were 50% GM. Despite this, Farmer Y was not displeased because her crops were growing far better than usual. Identify one ethical issue with the situation. (1 MARK)

Question 16 (7 MARKS)

An experiment was carried out by students to test the effect of temperature on the growth of bacteria. Bacterial cells were spread onto plates of nutrient agar that were then kept at three different temperatures: –10 °C, 15 °C, and 25 °C. All other variables were kept constant. The experiment was carried out over four days. The nutrient agar was observed every day at the same time and the percentage of nutrient agar covered by bacteria was recorded. At the conclusion of the experiment, the results were recorded in a table.

Time (days)	Percentage of nutrient agar covered by bacteria at three different temperatures		
	–10 °C	15 °C	25 °C
0	0	0	0
1	0	5	10
2	0	10	20
3	0	15	40
4	0	20	60

a Identify the independent and dependent variables. (2 MARKS)

b State a hypothesis that is supported by these results. (1 MARK)

c Suggest two variables that would have to be kept constant in this experiment. (2 MARKS)

d Two of the students, Mimi and Diego, wanted to reduce the possibility of personal errors affecting the results. Mimi said that they could do this by getting multiple students to estimate the percentage of nutrient agar covered by bacteria, then taking the average. Diego thought it would be better to include a negative control group. Name the student who is correct, and explain your choice. (2 MARKS)

Adapted from VCAA 2019 Section A Q7