Rewarding Learning

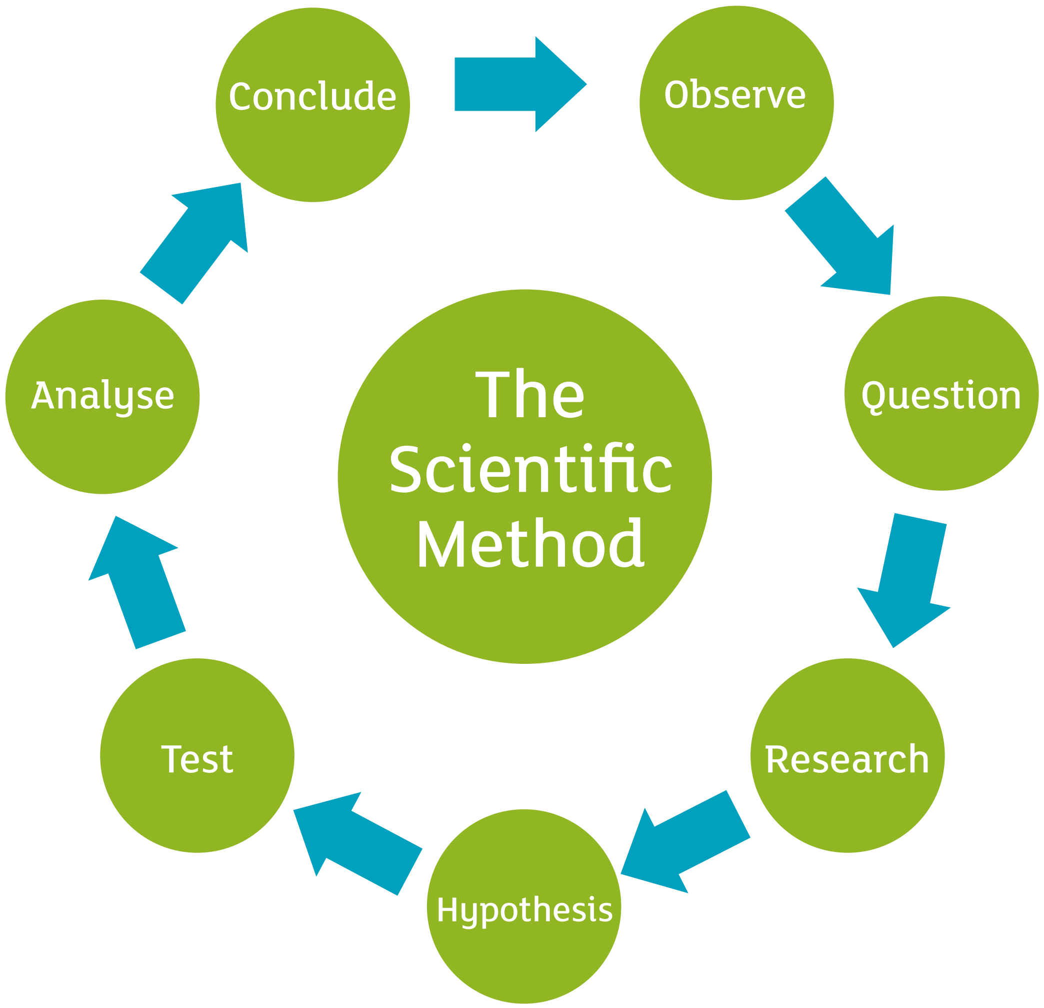
eGUIDE//

Life and Health Sciences

Scientific Method, Investigation, Analysis and Evaluation

Content

The Scientific Method



Learning outcomes

The purpose of this document is to help increase understanding and provide guidance and support for teachers delivering this core unit.

This document includes a range of suggested activities, discussion points and online resources to assist classroom teaching.

Aspects of this document may also be beneficial to teachers of other Life and Health Sciences AS and A2 coursework units.

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1 Introduction to scientific method

At the core of any science lies a problem-solving approach called the **scientific method**. This is a rigorous method for obtaining knowledge and understanding about our world.

There are plenty of examples of the use of the scientific method in history, for example in the development of vaccines, and in the fields of astronomy and medicine as well as many other areas.

The scientific method has some basic steps. Sometimes these may be labelled/ordered slightly differently but they always follow the same approach:

- Make an observation.
- Ask a question.
- Do some research.
- Form a hypothesis.
- Test the hypothesis (by conducting an experiment).
- Obtain and analyse the results.
- Write a conclusion.

The scientific method is used in all areas of science and this core approach helps scientists find logical answers to questions or problems that are **supported by evidence**.

Student activities

- Research and present an example of the scientific method observed in science history.
- Before looking at each step in the scientific method in more detail, use the following links to watch some short videos on the topic.

  Steps of the Scientific Method in 3 Minutes - YouTube

  The Scientific Method: Steps and Examples - YouTube

  The Scientific Method: Steps, Terms and Examples - YouTube

- The following articles provide some guidance on misunderstandings of the scientific process and also help with some of the vocabulary used throughout this document.

  Tips and strategies for teaching the nature and process of science (berkeley.edu)

1.1 Making an observation

This is often the first step of the scientific method.
A good scientific observation should be **objective** and **free from bias**.

The observer (who in this case is the student/scientist) must remain neutral during the observation and not approach the observation with preconceived ideas or opinions.

The observer should not be trying to prove they are right.

Question: *How does a scientist make observations?*

A scientist observes by obtaining knowledge from the world around them through their senses or by recording data using scientific equipment. They don't approach the observation with preconceived ideas as this will lead to bias. Experimental detail may then be overlooked or discounted as irrelevant.

Discussion: *How does a student begin to make scientific observations?*

Here are some steps to help students observe an area of scientific interest:

- Get to know the subject or area of interest by doing some background reading and **research**.
- Slow down and **observe critically** what you are finding through your research.
- **Record any observations** that are of interest and spend time thinking about them.
- **Think about questions** that could be asked about the observations.

Student activity

Share some science observations with a partner. Would any of your observations lead to a good scientific investigation?

Here are some observations to get you started:

a) Soap is used in handwashing.

b) Food goes mouldy quicker in warmer weather.

c) Cars skid more on icy roads.

d) De-icer spray uses rubbing alcohol.

1.2 Asking a question

Questions are an essential part of science. A scientific question is one which asks about the world around us and can be **tested**.

Question: *What is a good scientific question?*

A good scientific question is **defined, measurable and controllable.**

It should be answerable through observations, experimentation, or collection of data.

Question: *What is a poor scientific question?*

Questions that are based **on values, or opinions on right or wrong**, do not make good scientific questions.

Discussion: *How does a student begin to ask good scientific questions?*

- **Students should begin by asking broad questions** about a subject and reject any questions that cannot be answered either by observation or by collecting data.
- Now they should **ask more specific questions** that can be investigated in turn.
- The questions should be stated in a way that allows them to be answered by **completing an experiment**.

For example.....
What is the relationship between voltage and current in a wire?

What factors affect the respiration of yeast?

What is the effect of increasing the temperature on the rate of a reaction?

Student Activity

Review the science observations from the activity on page 5.

Can you think of any good scientific questions that could be tested?

Here is an example of a question with bias:

"Do dogs make better pets than hamsters?"

Can you identify what makes this question biased?

The question is also untestable.

Can you identify what makes this question untestable?

Answers

The question is **biased** because it is phrased in such a way that it already suggests that dogs are better pets than hamsters.

This question is also not testable because everyone will not agree on what the term *'better pet'* means?

Is the pet better because it is more interactive?

Maybe better means the pet will live longer or can go for walks?

1.3 Doing some research

It is important to do some scientific research before forming a hypothesis which will eventually become the cornerstone for developing the question into a plan.

In this A2 1 unit, research is formalised and presented as a **'referenced literature review essay'.** The literature review essay:

1. summarises previous research on the chosen area;
2. analyses the information; and
3. discusses its relevance to the planned experiment.

Question: *How does a scientist complete research?*

A scientist will begin by demonstrating knowledge and understanding about their chosen subject area. Next, a scientist will research, identify and evaluate similar experiments already carried out by others, describing how their investigations may be linked. Finally, they will analyse their research and use it as a starting point for new ideas.

Discussion: *How does a student begin their research?*

- **Define the chosen area or field of research.**
- Identify the **key concepts** and perhaps **create a list of key terms or concepts.**
- **Search creatively.** The internet is not the only place research can be conducted, students can research using textbooks, by asking professionals or reading research journals. Magazine and newspaper articles also contain information although neither of these sources will go into much scientific detail.
- **Compile a list of references** whilst completing the research.

1.4 Forming a hypothesis

A scientific hypothesis is a **testable explanation for an observation.**

The main purpose of a hypothesis is to create predictions about the future experiment. A scientist will then carry out those experiments to see if their results agree with the predictions.

Often, a hypothesis is described as 'an educated guess' however, it is based more on observation and research, and should be **justifiable with knowledge.**
A scientific hypothesis **does not have a predetermined outcome**. The hypothesis will either be supported or refuted by the evidence gained through experimentation.

A scientific hypothesis should also allow something to be **falsifiable**. That means it should be able to be proved wrong as well as being able to be proved right.

Some scientific hypotheses are called **null hypotheses.** These hypotheses state that there is **no relationship between the independent and dependent variables**. This can be a useful step in weeding out the factors which will and will not influence the outcome of an experiment.

When a null hypothesis is rejected then an **alternative hypothesis** is required. An alternative hypothesis defines that **there is a statistically important relationship between two variables**.

Question: *How does a scientist create a scientific hypothesis?*

A good hypothesis should be able to be **tested.**

It should include an **independent variable** (the variable to be changed) and a d**ependent variable** (the variable to be measured). Other variables (the **controlled variables**) should be kept the same.

The **variable should be able to be changed ethically without causing harm**.

Discussion: *How can a student create a good scientific hypothesis?*

Here are some questions for students to consider when forming a hypothesis:

- Can the **independent and dependent variables be identified** in the hypothesis?
- **Can an experiment be designed** so that it will establish a relationship between these variables?
- **Can other variables** that might have an effect on the **outcome be controlled?**
- **Can the experiment be repeated** to get the same results?
- Can the experiment be **carried out safely?**
- Can the experiment be **carried out ethically?**

Vocabulary check

The difference between a hypothesis and a prediction

A prediction is a statement about something that might happen in the future based on observations or existing evidence.

A prediction is the outcome which will be observed if the hypothesis is correct.

*The difference between these two terms is that **a hypothesis will always have an explanation or reason based on knowledge, whereas a prediction does not have any explanation**.*

Look at the following statements:

Statement 1
'Sugar granules will dissolve in water faster than sugar cubes.'

Statement 2
'The larger the surface area of sugar, the faster it will dissolve in water.'

Statement 1 is a prediction. It does not provide any explanation as to why the sugar granules will dissolve faster.

Statement 2 is a hypothesis. It is more explanatory than statement 1. It is also testable. The surface area can be changed (the independent variable), the time taken for the sugar to dissolve can be measured (the dependent variable) and the solvent, its volume, temperature and the mass of sugar can be kept the same (the controlled variables).

Student Activity

1 Discuss the following and consider which of these hypotheses could lead to an experiment to test the hypothesis?

For the examples which will not lead directly to an experiment, can you think of any changes in wording which might improve the hypothesis?

a) A person who only eats take away food will gain weight.
b) All objects dropped from the same height will hit the ground at the same time.
c) An object projected at a larger angle will have a larger horizontal range.
d) Larger mass vehicles will take longer to stop.
e) Metals with a single valance electron with have a larger conductivity.
f) A person who goes to bed earlier will have better-quality sleep.
g) Eating probiotic yogurt will improve gut health.

2 An example of an untestable hypothesis is, "eating apples will make people healthier". What are the difficulties associated with testing this hypothesis?

Answers

1 a) ***A person who only eats take-away food will gain weight.***
It is not ethical to test on people. You cannot control other variables easily.

b) ***All objects dropped from the same height will hit the ground at the same time.***
This can be tested.

c) ***An object projected at a larger angle will have a larger horizontal range.***
This can be tested.

d) ***Larger mass vehicles will take longer to stop.***
This can be tested, but not using large vehicles.

e) ***Metals with a single valance electron with have a larger conductivity.***
This can be tested.

f) ***A person who goes to bed earlier will have better-quality sleep.***
You would need to quantify the dependent variable, what exactly is meant by the term 'better-quality sleep'? It is difficult to control other variables.

g) ***Eating probiotic yogurt will improve gut health.***
This can be tested.

2 There are too many questions not addressed by this statement:

How many apples are required to affect the 'healthiness' of a person?

What is meant by the term healthy?

Does 'healthy' mean less disease, lower BMI or even fitter?

Is 'healthiness' referring to mental health?

Will the subjects being investigated be truthful about eating an apple a day?

Will the experiment be affected if they eat more than one apple a day? What about the other foods they eat, will they have an effect?

Is it ethical to ask a group of people not to eat any fruit in their diet?

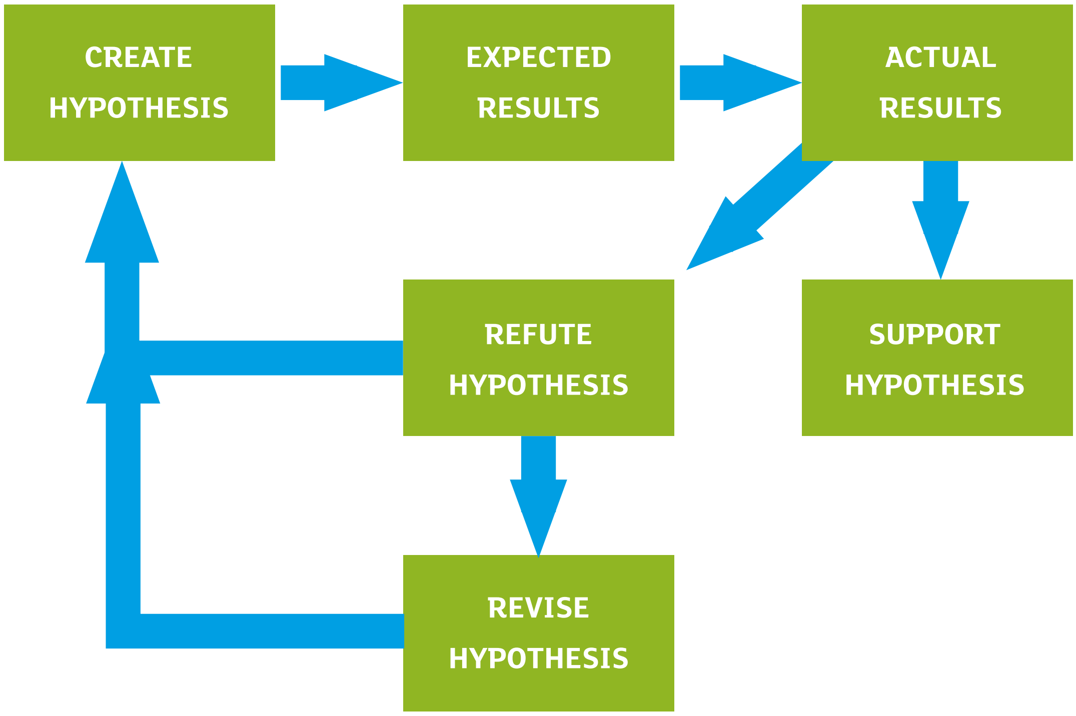
1.5 Testing the hypothesis

After a hypothesis is created, it needs to be tested scientifically.

Scientists do this by conducting experiments. **The aim of these experiments is to determine whether the observations agrees with or contradicts the hypothesis.**

Scientists need to check if the hypothesis is correct, and if what they expect to see, does match what is actually observed.

This process can be best demonstrated using the following flowchart:



The process of repeating steps is called **iteration**. Iteration builds in refinement and improvement through trials and finishes when scientists are satisfied they have reached an end result or conclusion.

Question: ***How does a scientist test a hypothesis?***

A scientist collects suitable data by **designing an experiment which changes only one variable, and identifies and controls all other variables**. Data is then collected and **analysed against the expected outcome**. This will then lead to **refinement and further experiments** until the scientist is satisfied that the data collected is **accurate, valid and reliable**.

Vocabulary check

The difference between validity, reliability and accuracy.

Validity relates to the appropriateness of the experimental method. Several aspects of the experiment can contribute to validity for example, the suitability of the equipment, the design of the experiment, and the way the results are analysed.

Reliability refers to the consistency of a measure, i.e. how close repeated measurements are to each other. Reliability can be achieved through repetition. The more similar repeated measurements are, the more reliable the results.

Random errors affect reliability. A random error is usually made by the person carrying out the measurement. For example, reaction time errors and parallax errors (a meter reading looks different when read from different angles). These random errors may be slightly larger or slightly smaller than the actual measurement. If random errors are removed, reliability will improve. Digital equipment such as digital meters, sensors or light gates can reduce the effect of these errors. If random errors cannot be removed then repetition and analysis of results will help reduce the effect of random errors.

The **accuracy** of an experiment is how close the final result is to the correct value. Accuracy can be improved through choosing the most accurate measuring equipment and reducing **systematic errors**. An example of a systematic error is faulty equipment that does not reset to zero, therefore all readings taken will be either too high or too low by the same amount. Accuracy cannot be improved by repeating the experiment, unless the cause of the error is removed or method improved.

Discussion: *How can a student test their hypothesis?*

The first step will be to **design a valid experiment** which will allow the hypothesis to be tested.

Then they need to i**dentify all the variables** and ensure only one variable, the independent variable, is changed. Students need to decide exactly what will be measured; this is called the dependent variable. The independent should have a suitable range of variation.

The remaining variables, the controlled variables must remain the same throughout the experiment making the experiment reliable.

The next step will be to **write a procedure** which outlines the **exact steps** to be taken during the experiment. This allows **others to repeat the experiment** to see if they agree with the results.

The procedure should include **an outline of the analysis of results and statistics** that is intended to be completed after results are collected.

The procedure should **take account of safety**. Students will need to consult **CLEAPPS** student safety sheets and hazcards and refer to them in their **risk assessment** (where applicable – also include in references). Risk assessments should be presented in **table format** and identify **ALL physical, chemical and biological** risks **associated with the experiment.** All **chemicals, including their concentrations and volumes/quantities** should be stated along with any risks associated with **disposal.**

Now it is time for students to **record some measurement**s. If, during the experiment, students notice variables which are difficult to control or measurements which are difficult to collect accurately they will need to **adjust their procedure and repeat the experiment again**. This is what is meant by the term **trialling**. **Trials allow students to research the optimum conditions to observe the best set of results**.

The data collected during each trial should be **recorded** in the lab book **and reviewed** until students are satisfied that they have come up with a procedure which is **valid, accurate and reliable**. **This could take a large number of trials to achieve so teachers should guide students appropriately**. Each trial should include a **detailed procedure and risk assessment. All results collected during a trial should be included. Both quantitative (tables) and, where appropriate, qualitative (sketches or photographs of results/observations) should be included along with a discussion on how these results will be interpreted and evaluated.**

Here are some questions for students to consider in their experimental design:

- Is the experiment **suitable?**
- Can the independent **variable be varied sufficiently?**
- Does the experiment **test what it is meant to test?**
- What is being **measured?**
- Is the **equipment suitable** and can it take **accurate measurements?** If the equipment is not suitable or the measuring equipment is not accurate enough then the measurements will not be accurate.
- **Is the equipment calibrated** to remove systematic errors?
- **Will the measurements be precise?** Is the measuring instrument most accurate? This will reduce random errors when taking readings.
- **Are there any assumptions and are these assumptions valid?**

For example:

... air resistance can be ignored

... friction remains constant

... the temperature doesn't change

If the assumptions are not satisfied, then there will be more than one variable changing during the experiment and the measurements will be invalid.

Does the experiment require a control?

The function of a control group is to act as a point of comparison, by ensuring that the variable under examination is the thing responsible for creating the results of an experiment.

Is the experiment repeatable?

If a measurement is repeated, will the outcomes be similar.

Are there factors that will be required to be trialled before a final experiment is completed?

Which statistical tests will be used to analyse the data?

These are the steps involved in the design of an experiment (DoE). For the purposes of students at this level, Design of Experiment c**an be summarised as** planning/conducting an experiment that i**s appropriate for their chosen aim/hypothesis**.

A Quick Guide to Experimental Design | 5 Steps & Examples (scribbr.com)

Student Activities

1 Research errors using the following documents and videos:

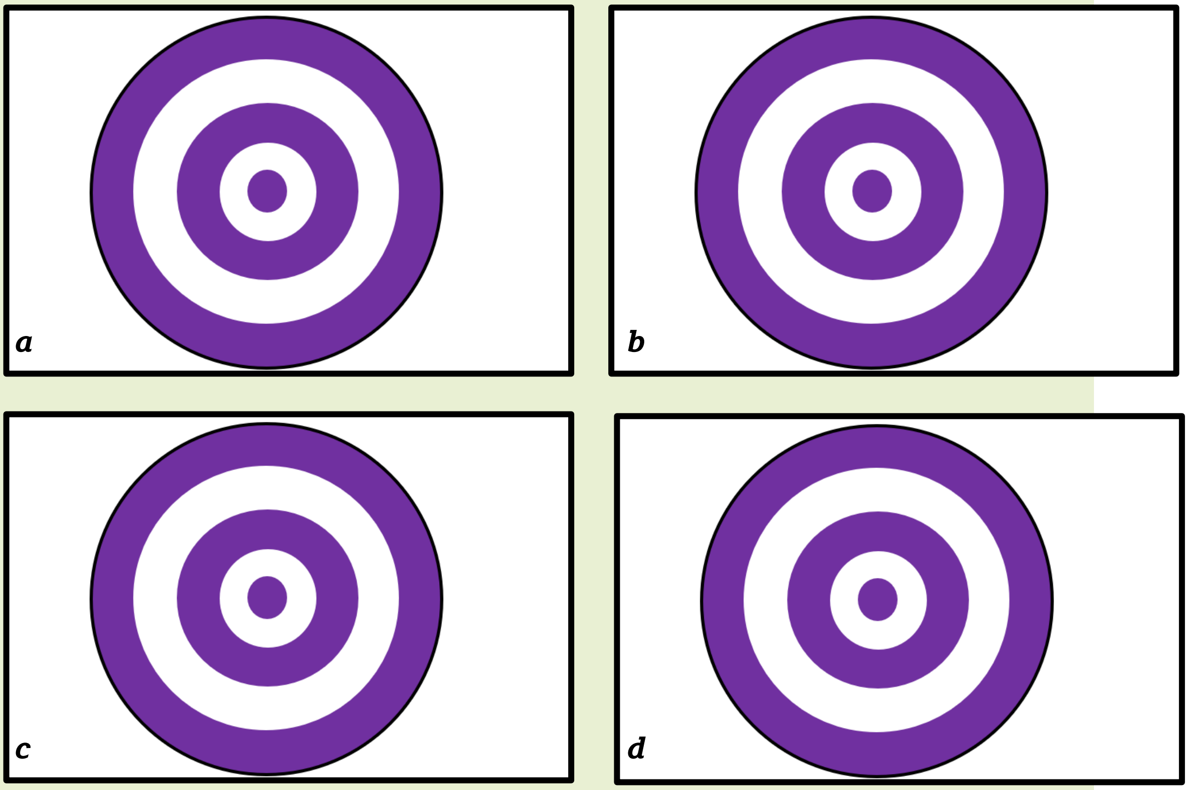
Systematic vs Random Errors in Physics | Part 3 of Physics Skills Guide (matrix.edu.au)

Experimental Process and Data Collection for the Scientific Method - YouTube

Experimental Design - Data Collection - YouTube

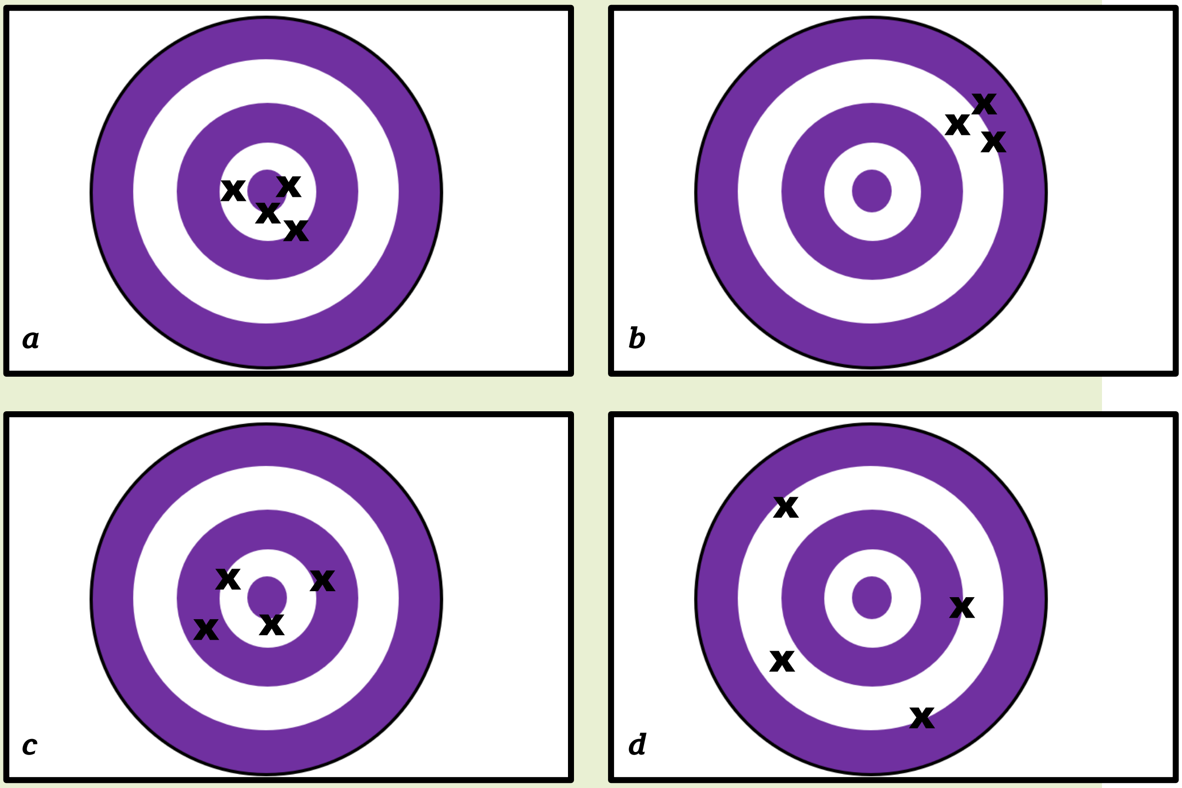
2 Draw x's to represent darts on the following dartboards to demonstrate the following:

a High accuracy and high precision
b Low accuracy and high precision
c High accuracy and low precision
d Low accuracy and low precision



Answers

2 a High accuracy and high precision
b Low accuracy and high precision
c High accuracy and low precision
d Low accuracy and low precision



1.6 Analysing the results

Analysis is a summary of the results of the experiment, and how those results match up to the hypothesis.

The data collected is analysed, discussed and interpreted. There is an **explanation** as to whether the results **support** the hypothesis. The analysis **evaluates** the experiment, identifying **sources of error** and factors which were beyond the control of the experiment and **suggests improvements**.

Negative results are results that **do not support the hypothesi**s and nullify the aim of the research. Negative results **are also important**, and they contribute to our knowledge of the topic as much as positive results do. When published, they prevent unnecessary duplication of experimental work. Sometimes negative results contribute something significant to the scientific community, for example the Michelson–Morley experiment. Often scientists and publishers are reluctant to publish negative results due to perceived shame or lack of scientific interest.

Question: *How does a scientist analyse their results?*

Whilst collecting data from an experiment, a scientist will usually carry out some initial data analysis to make sure that the observations meet expectation. This will ensure the procedure is working well or allow for early interventions if there is a mistake in the procedure. Data is also analysed before repeating the experiment and, during trials, improvements will be made to the experimental design before further repeats.

Scientists then look at the data from various perspectives and organise the data visually and mathematically to identify trends.

Lastly, the data is put it into context. This involves expressing the data relative to other similar data (identified during literature review). In this way, the data becomes more informative. If the experiment was similar to, or an improvement of an experiment completed by another scientist, the data collected will be directly compared to the previously published data.

Discussion: *What are the key points to consider when analysing results?*

- An analysis should begin by **discussing what happened during the experiment**. Outline the steps taken and the data collected.
- Students should look carefully at the data collected and discuss why they got those results. Their **data** should be **organised** in tables, graphs or other visual displays such as sketches or photographs. Then they should **apply some statistical tests**. These tests will determine the relationship between the independent and dependent variables and **provide statistical support to the results.**
- **Students should then relate the data to the hypothesis** by looking for patterns in the data that might support or negate the original hypothesis. If their results do not make sense, they will need to explain why they think this has happened. Unexpected results are not necessarily a bad thing - maybe incorrect equipment or an incorrect method was used. Maybe there were other factors that were not taken into consideration at the time that might have contributed to unexpected or incorrect results. The key point from a scientific perspective is that the student provides a considered analysis as to why something has or may have happened.
- **Students should not change the hypothesis, even if the analysis does not match the evidence collected.** Instead, students should discuss whether they accept or reject their hypothesis.

1.7 Writing a conclusion

A conclusion is the last section in a scientific report (not including References/Bibliography or Appendices). It summarises the points of research as discussed in the previous sections.

Question: *How do scientists write a conclusion?*

A scientist will firstly address the findings of the experiment. They will then discuss the contribution of the finding to the field of study. This will help provide context to the findings. They will outline any challenges which occurred during the experiment and provide suggestions for future research. Lastly, they will want to provide real world applications for the newly discovered knowledge.

Discussion: *Key information that should be included in a conclusion.*

- Refresh the readers on the main points of the research to remind them about what has been discussed.
- State the most important outcomes of the experiment. These outcomes may have been stated previously, but students are still required to clearly state them again in the conclusion.
- Discuss any limitations in the method including any impact on the results.
- Suggest improvements to the experimental design.
- Mention any recommendations for additional research on the subject in future.
- Demonstrate how the findings relate to the real world.

Student Activity

Review the following websites which discuss how to write a conclusion.

[How to Write a Science Conclusion (premiumessays.net)]

Write a list of dos and don'ts to help a student write a conclusion.

Dos and don'ts

- Before you start writing a conclusion, do take time to read through your work so far to identify the main points. Be brief when summarising these main points.
- Do not bring in a new idea or point that has not been previously discussed.
- Do re-state your findings clearly. Restate your hypothesis and link it to your findings, indicating if your results support your hypothesis or not.
- Do interpret the findings of your experiment.
- Do mention the shortcomings of your research.
- Do include any un-answered question/s.
- Do give any suggestions for further research on the subject area.

- Do include a discussion on how your results could be useful in any way in the real world?
- Proofread your work before submission to remove mistakes that might have been made while writing.

2 The literature review

In the assessment task for A2 1, research is formalised and presented as a **"referenced literature review essay"**. The literature review summarises the research; analyses the information, and discusses its relevance to the planned experiment.

A literature review has the following main aims:

- It **examines current literature** in the chosen area of interest.
- It **combines information from a variety of sources** to create a summary.
- It **discusses relevant concepts and theory** including **technical terms**.
- **It reviews prior research conducted by others and evaluates a variety of experimental work that is similar within the field of interest, relating it back to the student's chosen area of interest.**
- **It identifies any gaps in current knowledge and presents ideas for further research.**

A literature review should be presented in an **organised** way and should demonstrate understanding of the subject matter. It should be **structured** like any other essay, with an **introduction**, a **main section**, a **conclusio**n and **references**, as follows:

Introduction

The **introductio**n should **define the research are**a and provide an **appropriate context** for reviewing the literature. It should explain the **reasons for exploring the area of interest and set out the approach and order of the research**. It should outline what will and will not be included in the research.

Main Section

The main section should **organise the research into paragraphs** based on **common themes** or ideas. Each section should have **an appropriate heading. Tables and figures should be included** to support the text.

Conclusion

The conclusion should **summarise** the most important aspects of the research and **evaluate gaps** in existing knowledge. There should be a **concise evaluation of the reasons for selecting the scientific investigation to be carried out.** It should **identify other similar experimental work and evaluate its effectiveness, suggesting refinements of any experimental techniques reviewed.**

References

All sources used must be referenced (see section 5 Harvard referencing).

For further reading, take a look at the following web page.

[What is a literature review? - The Royal Literary Fund (rlf.org.uk)]

Here are some suggested key points to discuss with students before they write their literature review.

- It is not a list of information and should not contain everything ever written about the topic.
- It is not a book by book or website by website summary.

- It is not just background information relating to the investigation.
- It should not be just discussion about the experiment the student intends to carry out in the final report.
- It should tell the reader what knowledge and ideas have been established.
- Is should outline the strengths and weaknesses of previous research.
- It should include an evaluation of the strengths and weaknesses of this previous research, identifying any limitations and improvements in the experimental methods.

3 Technical writing in a report

A good report is easy to read. It usually has the following key features.

- Its **title** is precise and informative
- It is **organised** and has a logical format, with headings to indicate the content of each section and paragraphs to organise the information. The report is not overcrowded, and the font size is not too small.
- Any **diagrams, images, tables and graphs** that are included are meaningful, well-presented and clearly labelled.
- It uses **appendices** to organise useful support material.
- The form and style of writing is appropriate.
- It does not contain **unnecessary information**.
- It is **proofread** before submitting.

Here are some key points that could be discussed with students before they write their report.

Let's take each of the bullet points above and expand on each statement.

3.1 Title

The title should follow the three rules shown below:

1. It should **inform** the reader and give them a sense of what the research is all about. It should not be vague or general and it doesn't need to have fancy phrases. Steer clear of technical language that the reader will not initially understand.
2. The title should be more like a concise **phrase** rather than a sentence.
3. It is **punctuated** as follows: Capitalise the first letter of each word except for conjunctions, articles or prepositions. Colons or commas can be added to provide clarity but there should be no punctuation at the end.

Vocabulary check

Conjunctions, articles and prepositions.

Prepositions
A preposition is a word that shows position or direction such as up, down, in, out, around, over, among, and so on. E.g. The cat went under the table.

Conjunctions
A conjunction is a word that joins parts of a sentence such as for, and, nor, but, or, yet, so, since, although after, because, before, whose that which whichever, who whoever, whom whomever, what whatever .

Articles
Articles consist of the following words: a, an, the. Articles are used before nouns to add meaning.

Taken from:

Prepositions, Conjunctions, Articles, and Interjections | Writing Center (phsc.edu)

3.2 Organisation

Ideas and material should be organised into one of three categories:

1. **Important information** that is relevant to the objectives. This will go in the main section of the report.
2. **Borderline information** which might be useful to some readers but not necessary, or is necessary but will break up the flow of the report should be placed in appendices at the end of the report.
3. Information which may be interesting but **not relevant** to the objectives should be set aside to check later.

The main text material should be ordered logically.

Headings

Headings, should be used to indicate importance and it can be useful if their size relevant to the main text matches importance, e.g.

1. MAIN HEADING

1.1 Lesser Heading

1.1.1 Small heading

Paragraphs

Good style involves varying sentence length. Short sentences provide a clear, easy-to-read style for factual information. Where information needs to be compared with other information, longer sentences can work better. Paragraphs should be used to make the report more readable. Several paragraphs on a page with resulting spaces encourage reading, while a long block of text is off-putting.

3.3 Diagram, images, tables and graphs

Diagrams and tables can add meaning and interest to the report.

Diagrams should be **relevant to the text**. They should be placed close to the text that it refers to. If the diagram contains important information, this information should be discussed in the text. If students include information in a diagram format that is not their own work, and use it without discussing it or referencing it, the work they present is not their own which could lead to problems.

Diagrams must be **clearly referenced** in the text using the first number of the section in which the diagram appears, and then after the decimal point, the sequential number, e.g. Figure 3.7. **Figure references are written below the diagram. A short description of what the diagram shows** should also be included (as shown).

It is important for students to remember that if they use an online image such as a photograph or diagram, it is the intellectual property of another person and **needs to be cited and referenced** in their references/bibliography.

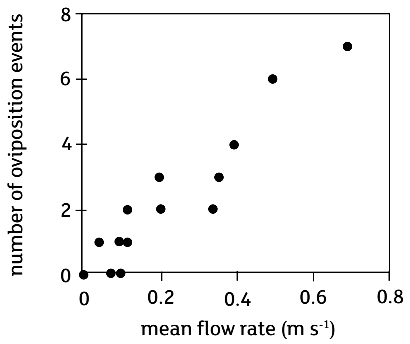


Figure 2. The relationship between flow rate and the number of oviposition events for the 14 weed patches at the main study site.

Tables

Tables should be clear and meaningful to the reader. Units should be included in the column headings. Students should consider if the reader needs all the data or could some of it be put in an appendix? **Table headings are usually written above the table and follow the format above for figure labelling**.

A description of what the data in the table represents should also be included.

Raw Material Turnover Ratio:

Year	Sales/£	Raw Materials /kg	Ratios
2006	2077.34	56.25	36.930
2007	2257.87	92.97	24.286
2008	2283.82	129.95	17.575
2009	2952.69	143.04	20.642

Table: 4.15

3.4 Appendices

Appendices should be used to remove from the main text all information which is not needed by the majority of readers.

In the main section of your report, students should indicate when they are referring to an appendix by **citing it in parentheses**.

For example:
The interview conducted in advance showed that everyone walked at least 5000 steps daily. (See Appendix B).

Examples of information that could be added to an appendix include:

- Raw data from tests
- Technical figures, graphs or tables
- Maps, charts or images
- Letters or emails used in research
- Sample questionnaires or surveys
- Full interview transcripts

Appendices should be placed after the bibliography or reference list. They should be divided into sections and each new appendix section should start on a new page. They are labelled with a letter or number, along with a title to indicate content (Appendix A: Data collected during initial survey, Appendix B: Equipment manuals, etc.). Any appendices should be included in the table of contents at the beginning of the report. Appendices do not count towards an overall word count.

3.5 Form and style of writing

Proformas are provided for students to use when writing up their investigations. There are many guides available for scientific writing however there are a few key areas that students should do at this level:

- Use relevant scientific terminology but keep the language as simple as possible;
- Keep things impersonal so don't use 'I', 'we' or 'you';
- When describing things that have already taken place – for example when writing up the procedure or method – past tense must be used as (obviously) students are describing what has already taken place.

3.6 Unnecessary information

It can be tempting for some students to include almost everything and anything that is vaguely relevant when writing up their literature review essay or investigation report. This can lead to huge portfolios that are difficult to follow and subsequently mark as they may contain lots of irrelevant or unnecessary information. This is bad practice and must be discouraged. **Good scientific writing does not include:**

- **unnecessary**
- **irrelevant or**
- **poorly presented material.**

Along with spelling, punctuation and grammar, quality of written communication (QWC) also considers suitable form and style of writing as well as the ability to organise information clearly and coherently. Including any unnecessary or irrelevant material will distract from the whole purpose and flow of a chosen investigation. If a portfolio is overly large and poorly organised, then it can be very difficult for the reader to follow or find relevant information. Therefore, regardless of the quality of the investigation a portfolio containing unnecessary information would be considered as a lower standard piece of work.

3.7 Proofreading

Finally, **students should read their report for spelling or grammatical errors.** The best advice is to do it with fresh eyes. Leave the report for at least 48 hours after finishing it if possible, and then give it a final check.

Activity

The activity below was sourced from the following online article:

technical-report-writing.pdf (theiet.org)

Below is an example of writing by a qualified and experienced engineer. Suggest some improvements.

At present on the XYZ sub-station we have no facility to supply 12000 amps required for the new plant from the existing spare O.C.B.'s, this will require the removal of some of the old existing oil circuit breakers and replacing with new vacuum circuit breakers (VCBs) since we cannot uprate the existing VWX equipment which is of course 1937 vintage, the proposal for this would be as follows….

Answer

Revised example:

On the XYZ sub-station board, we are unable at present to meet the demand (1200 amperes per phase) required to operate the new plant using the existing oil circuit breakers (OCBs). Spares are not available and the old equipment cannot be uprated. We therefore suggest replacing some of the existing switchgear with new vacuum circuit breakers (VCBs). The proposal is costed below….

The improvements have been made by:

1. moving 'at present' so emphasis is on the substation board.
2. replacing unnecessarily complex language 'we have no facility' with 'we are unable to'.
3. Replacing amps as is not a recognised abbreviation for amperes.
4. Spelling out the acronym before using it (OCB).
5. Breaking up the text into shorter sentences for ease of reading.

4 Handling Data

The CCEA LHS factfile Bridging Mathematics is a useful document to read in conjunction with this chapter:

Tables

Tables are used to **organise and store data**. One of the greatest advantages of tables is it makes it **easier to spot trends and anomalies**. Tables can be used to store both quantitative and qualitative data.

Here are some key points that could be discussed with students when they are creating tables:

- Does the table have a **title?** This is called the **legend**.
- Does each **column have a heading which includes any units**? It can also be useful to include powers of 10 in the table headings.
- Is the data in each column listed to the same level of accuracy? Is the level of accuracy consistent with the instruments used to collect the data?

Here are some examples below:

Table 4.1 Potential difference and current readings for a Thermistor at different temperatures.		
Temperature/°C	Potential difference/V	Current/mA

Table 5.2 Activity of Technetium – 99m against time		
Time/hr	Activity/ x10^2 Bq	Ln(Activity/Bq)

Graphs

Graphs are a visual means of representing data. They allow data to be represented in a way that is easier to spot trends, or identify if additional data is required, for example at a turning point of a curve. Graphs can also help identify outliers. Outliers or anomalies are data points that are not consistent with the rest of the data. When analysing data, it is important to identify outliers and deal with them so that they don't disproportionally affect the conclusion.

There are many different types of graphs, the most of which can be reviewed in this basic guide to graphs: **Data Analysis & Graphs** This link also contains a pupil check list for completing graphs.

Statistics

Statistics is the third way of examining data. It allows data to be analysed or compared objectively.

There are two broad categories of statistics: **descriptive statistics and inferential statistics.**

Descriptive statistics allows the data to be described, organised and summarised, for example when analysing test results collected over a year for one class of pupils.

For a review of several basic descriptive statistical calculations consult the general guides to Summarizing Your Data and evaluating Variance & Standard Deviation.

Inferential statistics involves analysing a sample of data and inferring information from that data. The data analysis can extend to a similar larger group of data. For example, instead of studying information from an entire population of a country, a smaller sample of the population is studied and then the results are extended to the entire population.

The following resource provides a table contrasting the differences between these two types of statistics:

Descriptive Vs. Inferential Statistics: Know the Difference - Science Struck

Some of the most basic types of statistical analysis required to be studied in this unit will already be known to students. Examples of these are mean, median, mode and probability. Other types of statistical analysis may be less known such as variance, standard deviation, normal distribution and confidence limits.

Median: Order the data from smallest to largest and determine the middle value (for an even number data set find the average of the two middle values).

Mode: The data value which appears most frequently. If two values occur most frequently then then it is called bimodal etc.

Mean: The average value μ.

Statistical Significance: If results are statistically significant, that means there is a very low probability of this occurring by chance. This must be proven through relevant statistical test/s.

Standard deviation: Standard deviation is a measure of how far a set of data is spread from the mean.

About 68% of all data results are within 1 standard deviation of the mean and 95 % of all result are within 2 standard deviations away from the mean. About 99.7% of scores are within 3 standard deviations of the mean. This can be observed in the normal distribution curve on the next page.

If a set of data has a mean of 10 and a standard deviation of 2, then 68% of all the data values will lie between 8 and 12 and 95% of the data values will lie between 6 and 14.

The equation used to calculate standard deviation is:

$$\sigma = \sqrt{\frac{(x_1 - \mu)^2 + \cdots + (x_N - \mu)^2}{N}}$$

Where σ is the standard deviation, x_1 .... x_N represents each value of data and μ is the mean.

To calculate standard deviation of a whole population of data using Microsoft excel, the formula used is =STDEV.P(x_1:x_N)

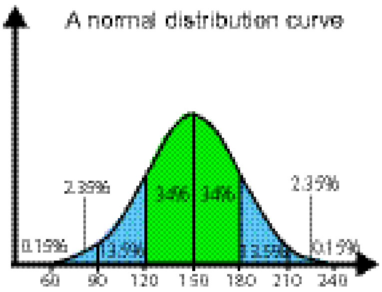
The **sample standard deviation** (the standard deviation of sample of the population) can be used to make estimates about the population standard deviation.

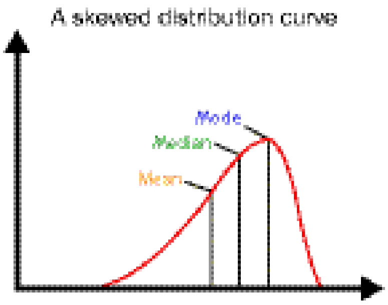
The equation used to calculate the sample standard deviation is:

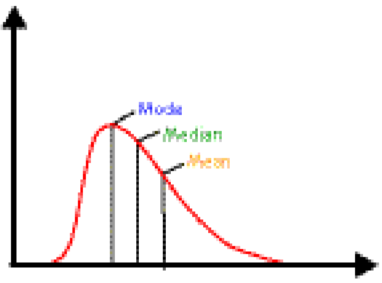
$$\sigma = \sqrt{\frac{(x_1 - \mu)^2 + \cdots + (x_n - \mu)^2}{n-1}}$$

To calculate standard deviation of a sample of the population using Microsoft excel, the formula used is =STDEV.S(x1:xN)

Normal distribution: In a normal distribution, data is symmetrically distributed with no skew. When plotted on a graph, the data follows a bell shape, with most values clustering around a central region tapering off as they go further away from the centre. When the standard deviation is large then there is a wide curve with a flat peak. This shows the data is very spread out. It the standard deviation is small then the normal distribution curve is







Further information on standard deviation can be found here:

Standard Deviation | A Step by Step Guide with Formulas (scribbr.com)

Below are some short videos on statistics and how to interpret a normal distribution curve:
What is a Bell Curve or Normal Curve Explained? - YouTube
Teach me STATISTICS in half an hour! - YouTube

Variance: Variance, σ^2 is another indicator of the spread of the data.

For the whole population of data, the formula used to calculate variance is:

$$\sigma^2 = \frac{(x_1 - \mu)^2 + \cdots + (x_N - \mu)^2}{N}$$

To calculate variance of a whole population of data using Microsoft excel, the formula used is =VAR.P(x1:xN)

For a sample of a population, the formula used to calculate variance is:

$$\sigma^2 = \frac{(x_1 - \mu)^2 + \cdots + (x_N - \mu)^2}{N-1}$$

To calculate standard deviation of a sample of the population using Microsoft excel, the formula used is =VAR.S(x_1:x_N)

Standard error: The standard deviation of the mean or standard error gives a measure of how much, on average, the sample mean differs from the mean of the population. The closer the sample mean to the population mean then the smaller the standard error. This means the sample mean is representative of the population mean.
The formula used to calculate standard error is:

$$\text{Standard error} = \frac{\text{Standard Deviation of the sample}}{\sqrt{N}}$$

Probability: The probability value or p-value (a value between 0 and 1) is a number which describes how likely the results would have occurred at random. The smaller the p-value the more likely the results are related and did not occur by random.

A *p*-value of 0.05 is the significant cut off point in most experiments.

A value of *p*-value of less than 0.05 means that there is less than 5% chance that the results happened randomly. The null hypothesis (no relationship between the variables) can therefore be rejected and the results can be said to be statistically significant.

A I-value higher than 0.05 indicates it is likely any differences observed between the data is down to random variation. There is not enough evidence to reject the null hypothesis and therefore the null hypothesis can be accepted.

Confidence limits: The confidence level is expressed as a percentage. A 95% confidence level means we can be 95% certain the data is correct; the 99% confidence level means we can be 99% certain etc.

To calculate 95% confidence limits the following formula is used:

Confidence limits = mean ± t(standard error)

The value of t can be determined from a table of values at p = 0.05 and n-1 degrees of freedom when the sample size is n. The link above (pg. 106) will provide a typical table of values for t.

Using this, a graph of bar chart with confidence limits can be plotted and interpreted.

Understanding Confidence Intervals | Easy Examples & Formulas (scribbr.com)

There are two other useful types of statistical tests:
The **t-tests** which is used when comparing variation for two distinct groups of data. More information on t-tests can be found here.

T-Test Definition (investopedia.com)

The **chi-square test** which is used to check if data fits an expected ratio.
More information on chi-square tests can be found here.

Further information each of the statistical tests above can be found in the CCEA A2 Biology textbook 2nd edition, pg. 280 – 283.

On the next page is a table showing an example of how to calculate some of the statistical tests listed previously using the following set of seven numbers 1,3,6,3,8,9,7.

Statistical test	How it is performed	Example	Value
median		1,3,3,**6**,7,8,9	6
mode		1,**3**,**3**,6,7,8,9	3
mean	$\mu = \frac{\sum x_i}{N}$	$\frac{1+3+3+6+7+8+9}{7}$	5.29
probability	P(A) = $\frac{number\ of\ favourable\ events}{total\ number\ of\ events}$	P (3) = $\frac{2}{7}$	0.286 or 28.6 %
Variance of all data values	The variance for a whole population of data: $\sigma^2 = \frac{(x_1-\mu)^2+\cdots+(x_N-\mu)^2}{N}$	$\frac{(1-5.29)^2+\cdots+(9-5.29)^2}{7}$	7.63
Variance of a sample of the data	The variance for a sample of the population of data: $\sigma^2 = \frac{(x_1-\mu)^2+\cdots+(x_n-\mu)^2}{n-1}$	$\frac{(1-5.29)^2+\cdots+(9-5.29)^2}{6}$	8.90
Standard deviation of all data values	The equation for population standard deviation (using all of the data) is $\sigma = \sqrt{\frac{(x_1-\mu)^2+\cdots+(x_N-\mu)^2}{N}}$	$\sqrt{7.63}$	2.76
Standard deviation of a sample of the data	The equation for the sample standard deviation (using a sample of the population) is $\sigma = \sqrt{\frac{(x_1-\mu)^2+\cdots+(x_n-\mu)^2}{n-1}}$	$\sqrt{8.90}$	2.98

How to decide which statistical tests to apply to data?

Refer students back to published scientific articles in the science field. They can then evaluate their data using similar tests.

This is a link to a good video on how to choose a statistical test.

Spreadsheets such as Microsoft excel can simplify the task of creating graphs and using statistics to analyse numerical data by performing the calculations. The link to this video provides a very comprehensive overview of using excel for a range of statistical analysis.

Student Activity

Further research on statistics can be found using the following resources:

An overview on statistics:

Experimental Design for Advanced Science Projects (sciencebuddies.org)

This resource provides additional information on what to do with outliers:

A Complete Guide for Detecting and Dealing with Outliers | by Rashida Nasrin Sucky | May, 2022 | Towards Data Science

Additional information about statistics is also available in the link below:

http://www.itl.nist.gov/div898/handbook/

5 Harvard Referencing

References **improve the credibility of a report**. A reference list also t**ells readers what sources have been used and how to find them**.

A reference list will **give credit to any work which was used in writing the literature review essay and report.** It also **demonstrates that student work is completed independently and is not plagiarised**.

A reference list, just like an appendix, does not contribute to a word count.

In Life and Health Sciences, the system of referencing used is **Harvard Referencing. Harvard** is the most common referencing style used in UK universities.

Vocabulary check

Bibliography and Reference list

A **Reference list** contains all the sources which have been cited in a report.

A **Bibliography** contains all the sources which have been cited in a report **as well as** all the information which was used for research - even if that material is not specifically cited in the report.

Referencing a book.

In **Harvard referencing, the author's surname and the year**, e.g. (Hawley 1996) are cited in-text.

Then **in the bibliography or reference list, the details of the author or authors (surname then initial), year of publication, title of publication, town or city of publication and publisher are given in full.**

Here are some examples taken from: [Guide to referencing using the Harvard system (bradford.ac.uk)]

Examples of citing in the text of your work: Burns and Grove (2005) or (Burns and Grove 2005); ACI Committee (2008) or (ACI Committee 2008).

Examples of bibliography references.

Burns, N. and Grove, S.K. (2005) The practice of nursing research: conduct, critique, and utilization. 5th edition. Elsevier Saunders.

Johnson, G., Hill-Smith, I. and Ellis, C. (editors) (2006) *The minor illness manual*. Abingdon: Radcliffe.

ACI Committee (2008) *Report on measurement of workability and rheology of fresh concrete, 238.* Farmington Hills: American Concrete Institute.

BFN 71 (2016) London: BMJ Group and Pharmaceuticak Press.

Referencing online resources.

The online material is cited in the same style as other sources, but **indicate it is online and provide the URL and the date accessed**.
E.g. **The IET (2019)** would be the in-text citation:

The Institution of Engineering and Technology's official website. [online] Available at http://www.theiet.org [Accessed 13 Mar. 2019] would be the bibliography reference.

Including page numbers.

If students use a direct quote from a source, or directly copy an image, they will need to include the page number where they found the quote or image. This will be included after the year in the citation and is separated by a colon. If however the information is written in their own words then they do not need to include a page number.

Students should be discouraged from directly quoting large amounts of important information, especially when there is no evidence of understanding (i.e., the information is not discussed or explained by the student).

Here is another example taken from: Guide to referencing using the Harvard system (bradford.ac.uk)

A Direct quotation example:

'The engineer is the driver of the engineering design. To achieve engineering success, an engineer needs to understand and avoid potential failures that may occur down the road' (Wang and Rosh 2000: 1).

A paraphrase example:

An engineer may have to overcome failure to achieve success (Wang and Roush 2000).

Example of citing in the text of your work for a direct quote-give the page number:
Burns and Grove (2005: 32).

Resources with more than one author.

In this case follow the following format to create an in-text citation:

(Davis 2019)	1 author
(Davis and Barrett 2019)	2 authors
(Davis, Barrett and McLachian 2019)	3 authors
(Davis *et al* 2019)	4 + authors

Cite all the authors in the bibliography or reference list.

When the author is unknown use the source's title.

If there is no date, then state 'no date' or 'nd'.

Citing more than one source at a certain point in the report?

The sources should be listed and separated with semicolons. The usual order is determined by the date of publishing with the newest publication coming last.

Online tools that can help.

There are plenty of online tools which generate both in-text citations and bibliography citations. Here is one website.

FREE Harvard Referencing Generator & Guide | Cite This For Me

The order of the bibliography and reference list.

A bibliography or reference list **appears at the end of the report** and should be written in alphabetical order (by the author's last name).

Here is an example of a reference list below. It was taken from A Quick Guide to Harvard Referencing | Citation Examples (scribbr.co.uk)

Reference List

Children, J.W. (2012) 'Social class in the Victorian novel', in David, D. (ed) *The Cambridge companion to the Victorian novel*. 2nd edn. Cambridge University Press, pp. 148-169.

Eliot, G. (2017) *Silas Marner*. Edited by Atkinson, J. Oxford: Oxford Universtity Press.

Levin, G. (2019) 'The Dickensian George Eliot', *Dickens Studies Annual*, 50(1), pp 48-65

Tolstoy, L. (2006) *War and Peace*. Translated from the Russian by A Biggs. London: Penguin

Universities often provide their own Harvard Referencing Guides as per below:

Ulster University Harvard Referencing Guide

QUB Harvard Referencing Guide

Referencing advice for students.

It will be very helpful to remind students to **make a note of references as they go along** so they can remember where the information that they use came from, especially if the source is a web page as the date accessed will be required in the reference.

6 Some Good Practice and other Tips

Presentation of portfolios

The A21 portfolio assessment task must be presented as **three separate pieces of work**:

1. Literature Review (Essay),
2. Lab book and
3. Report.

Practical Investigation ideas

Below is a list of ideas for A2 1 practical investigations. Ideally, Pupils should be able to choose their own investigation and are not limited to the examples below. However, teachers should **ensure that the range of investigation/s is appropriate and manageable within their school.**

Investigation into the speed of a rolling can

An investigation into the effect of differing light intensity on stinging nettle's leaf width.

Investigating antacids.

Investigating effectiveness of sanitiser.

Investigating the rate of anaerobic respiration in yeast.

Investigating the relationship antibiotics and the growth of bacteria.

Investigating moving bodies, e.g. collisions, objects moving down a ramp, projectiles.

Investigating the vitamin C content of different juices.

Investigating the quantity of sugar in fizzy drinks.

Literature Review

The Literature review essay must be a stand-alone document.

The Literature review should have four clear and distinct sections:

Introduction – This should provide an **overview** of the **field of study in context**. Students need to place their chosen field into a real-life context. It should identify any key terminology and discuss its meaning so a reader who is unfamiliar with the field of study can follow the work.

Main Section – This should provide information on **factors which need to be considered** when experimenting in this field. This should be broken into short paragraphs on each factor to be considered. It should also contain any theory which may be necessary for readers to understand the field of study. The main section should not refer to the actual experiment to be carried out at this stage. It should also contain **research into prior experimentation in the field**. The methods and equipment used to generate results should be discussed. There should be some **diagrams or tables** to support the essay, and these should have titles and figure headings.

Conclusion & Evaluation

This section should signpost the way forward, indicating the direction the student wishes to go in their research. The chosen experiment or research should only be discussed at this stage. There should be an evaluation of the methods used in the prior research. This involves students critically examining the research they discussed in the main section and evaluating its usefulness, accuracy, availability etc in a classroom laboratory situation. This evaluation of the experimental work leading to refinements of the methodology is an extremely important part of the essay and students will not be able to reach top mark band without this.

References/Bibliography

Students need to present their References/Bibliography as follows:

- At least 10 references, some of which should be referenced in the body of the work.
- The references need to be in Harvard style.
- They need to be presented in alphabetical order by surname.

If any of these marking points are missing, then students **cannot access top mark bands.**

Awarding marks to the literature review essay

Top marks should only be awarded to students who have fulfilled all the necessary criteria. It is not important that students discuss all theory or all factors, but more important that they include a good range of information written in their own words.

Essays which are collections of information without any contemplation of relevance and containing no discussion or evaluation should be awarded low mark band marks.

Essays should be written in the correct form i.e., **impersonal** form.

Students should be encouraged to be concise and avoid repetition. Where students submit excessive and **unnecessarily long** essays, the awarding of marks should reflect this as scientific writing should be concise and not contain unnecessary information.

Lab Book (also known as Laboratory Notebook)

The Lab book must be a stand-alone document.

The lab book is a place where students keep a **record of their learning as the course develops**. It is essentially a place for draft planning and recording information/results or observations from trials/errors/refinements and other notes or relevant information. It can also be used to provide evidence of the specification Learning Outcomes that are not evidenced elsewhere if necessary. Lab books are generally handwritten – they can be typed up if preferred but this is more work than necessary, although apps and other technologies are becoming available for this purpose.

Below is a list of items that must be contained in the lab book:

- Any **specification references which are not covered in the essay or report**.
- A **draft project plan which identifies milestones**. This draft project plan should be r**eviewed and updated** where necessary as the year continues.

- The **trials leading up to the experiment that will be written up in the final report**. Each trial should be recorded according to the **standards set out in AS1** and using the practical investigation proforma template:
  - Introduction indicating the purpose of the trial and any expected outcomes.
  - List of apparatus and assembled scientifically labelled diagrams or photographs. These diagrams should have titles and figure headings.
  - A thorough risk assessment with CLEAPPS and COSHH references, concentrations of chemicals and methods of disposal of chemicals and biowaste (as and where appropriate).
  - A very detailed procedure.
  - A scientifically presented table of results with appropriate figure heading and title.
  - Suitable scientifically presented graphs with appropriate figure heading and title.
  - Statistical tests and calculations which have been applied to the data collected.
  - Where appropriate, drawings or photographs (observations-qualitative data).
  - A conclusion which includes an analysis of errors, limitations and refinements leading to suggestions for possible future experiments.
- In a trial there should be some form of comparison between different values. **There should be a minimum of three detailed trials in the lab book**. Training required to allow the pupils to carry out the final project should not be counted as trials unless there are refinements gained from the training.
- A **final project plan**.

Awarding marks to the Lab book

Top marks should only be awarded to students who have fulfilled all the necessary criteria.

The awarding of marks should reflect the quality of the work in each section.

The writing style should not be penalised in this section.

Planting Science - Teacher Roadmaps - Lab Notebooks and Science Notebooks

Planting Science - Student Roadmap - What's in Your Notebook

Project Planning

A project plan is essentially a 'roadmap' that outlines 'what' (steps/tasks/resources) are required and 'by when' (timescales). If other people or organisations/groups are also involved in a project's delivery, then the 'by who' will often also be included. A good project plan is logical and can be easily followed, which allows everyone involved to clearly see **what is required** and **by when** (and **by who** where necessary), and therefore **progress can be tracked.**

Project plans can be complicated (e.g. a large construction or ICT project) or very simple (e.g. organising a night out, or decorating a room). Therefore, whilst creating a physical project plan may be an unfamiliar activity for students, everyone will have had experience of planning for something previously - even if just in their head or during a discussion with family or friends.

For Life and Health Sciences the key is that students understand what a project plan is, how to create one, and how to use and where necessary update it to keep track of everything that must be done to achieve something. Students must be able to logically and clearly consider the tasks/steps that are required up to final submission, including any resources they need (equipment etc) and the timescales that are necessary for completion of each step.

Specialist software can be used for more complicated projects but that will not be necessary for this unit. Spreadsheets are commonly used, or even a simple table in Word if necessary.

Draft Project Plan

For Life and Health Sciences unit A2 1 the draft project plan should outline identified tasks/steps and timescales that are necessary to complete the whole 'project'. In this case the whole 'project' is planning everything that is required right from researching and selecting a chosen investigation up to final submission to the teacher.

In situations where there may be a lot of steps or tasks, it can be useful to break areas down into milestones. **Milestones** are significant points or stages in a project – for example completing the 'Literature review' could be a milestone which then can be further broken down into all tasks required for the literature review such as research into the field of study and evaluating the experimental procedures completed by previous researchers. Other milestones could include the completion of 'trial experiments' which can be broken down to include the identification of variables (ensuring the best conditions are determined for the final experiment), considering resources, training on new equipment, dealing with errors, identifying and eliminating ethical concerns, learning about and practicing data analysis and creating risk assessments.

This draft plan should then be **refined** and **updated** where necessary (e.g. where tasks take longer than expected or further trials are required) - for this reason project plans are considered to be a 'living document' during a project lifecycle. A draft project plan is unlikely to be perfect because unforeseen things can and probably will happen causing delays or requiring a change. Therefore, part of 'managing' a project is the ability to identify when and what needs to be adapted and refined where necessary to bring things back on track.

Final Project Plan

The final project plan is the plan related only to the completion of the scientific investigation. This project plan should include health and safety, use of equipment and lab techniques, GLP and the accuracy and precision of results.

Project Planning tips for students

Students may initially find it helpful to start creating a plan using sticky notes. Identify each individual step/task required on a sticky note along with any resources required on other sticky notes and then place in a logical order on a desk or whiteboard where they can add or move things as required. In terms of timescales, it may help to identify the **absolute deadline** for the outcome to be achieved and work backwards and consider:

- Are there any steps missing or that are unclear?
- Can everything be achieved on time?
- Does the plan consider everything that is required (for example access to equipment, materials, Laboratory or Teacher time)?
- Is everything that is required available – for example materials or equipment?
- Is there sufficient time within the plan in case something goes wrong, or has to be changed or is delayed?

Written Report

The Written report must be a stand-alone document.

This report should be set out as per the 'Practical investigation report Proforma'.
The report should include:

- A **concise title**.
- An **introduction including an aim and hypothesis**. There should be a comprehensive explanation of principles, definitions, experimental techniques, theories and laws as appropriate.
- A **list of apparatus and scientifically labelled diagrams** which can include labelled photographs. These diagrams should have titles and figure headings.
- A **thorough risk assessment** with CLEAPPS and COSHH refences, concentrations of chemicals and methods of disposal of chemicals and biowaste (where appropriate).
- An **appropriate procedure** which has been carried out safely and accurately. **There must be teacher annotation to support the marks awarded as half the marks in this section are for the completion of the experiment in class**. The method should be detailed in full and accurately recorded. Any technical information required to explain how readings are taken should be discussed. Health and safety issues should be considered.
- A **complete set of quantitative results and qualitative observations** should be included and recorded in appropriate tabular and/or graphical format using appropriate headings and units.
- **Accurate calculations** to a suitable number of decimal places. Information on handling data handling can be found in the following teacher support document Bridging Mathematics.
- **Statistical tests** to enable a conclusion to be reached. If statistical tests are completed using data stored on a database then students should include any formula used.
- An **accurate and concise conclusion** that answers the objective.
- A **thorough error analysis** has been carried out with identification of the sources of error including the equipment used.
- An robust evaluation of the experiment including **limitations** with explanations; and
- Identification of **refinements** of the experimental techniques used.

References/Bibliography. Students need to present their bibliography as follows:

- At least 10 references, some of which should be referenced 'in-text' in the body of the work.
- The references need to be in the Harvard style.
- They need to be presented in alphabetical order by surname.

If any of the above points are missing, then students cannot access top marks.

Appendices are to be included at the end of the report. There should be at least **two appropriate** appendices which are **referenced** within the body of the report. Appropriate appendices do not include any material stored in the lab book or any of the report details listed above except for large volumes of data. Students should not include journals etc as a reader can access this information using the references/bibliography.

Suitable appendices include raw data if the data collected is so large it interrupts the flow of the report, statistical tests or statistical data sheets or descriptions on how to use specialist equipment. When evaluating the suitability of an appendix - it should be useful for the reader but not contain essential information required to be placed in the report.

If any of these appendix points are missing, then students cannot access top marks.

Awarding marks to the report

Top marks should only be awarded to students who have fulfilled all the necessary criteria. Reports should be written in the correct form i.e. using past tense impersonal form. Where students submit excessive and unnecessarily long reports, the awarding of marks should reflect this as scientific writing should be concise and not contain unnecessary information.

Annotating portfolio evidence

Annotating portfolio evidence is a requirement before submission.

When annotating coursework for A2 1, teachers are not required to identify AO1, AO2 or AO3 marking points. Teachers should instead **record the marks awarded and a brief indication of why mark bands have been awarded and why marks are removed**. Teachers should only use **red pen** when annotating scripts or performing internal standardisation. If students have not clearly identified their work with headings for each section, then teachers are required to identify this evidence (or where it is) throughout the portfolio so CCEA moderators can easily find the necessary evidence to support the marks awarded. Best practice would be to **ensure students create titles and headings throughout their work to create clarity**. This will greatly support teacher marking and assist the moderation process, because candidate evidence is clear.

Agreement Trials

CCEA will provide teachers with suitable guidance to ensure that specification and assessment criteria are as clear as possible. For this reason, it is **strongly recommended** that agreement trial materials which are notified to schools in the autumn term are **utilised each year,** so that teachers are fully familiar with assessment criteria and requirements.