Biology Units 1 & 2

Chapter 6 — Scientific investigation and primary data

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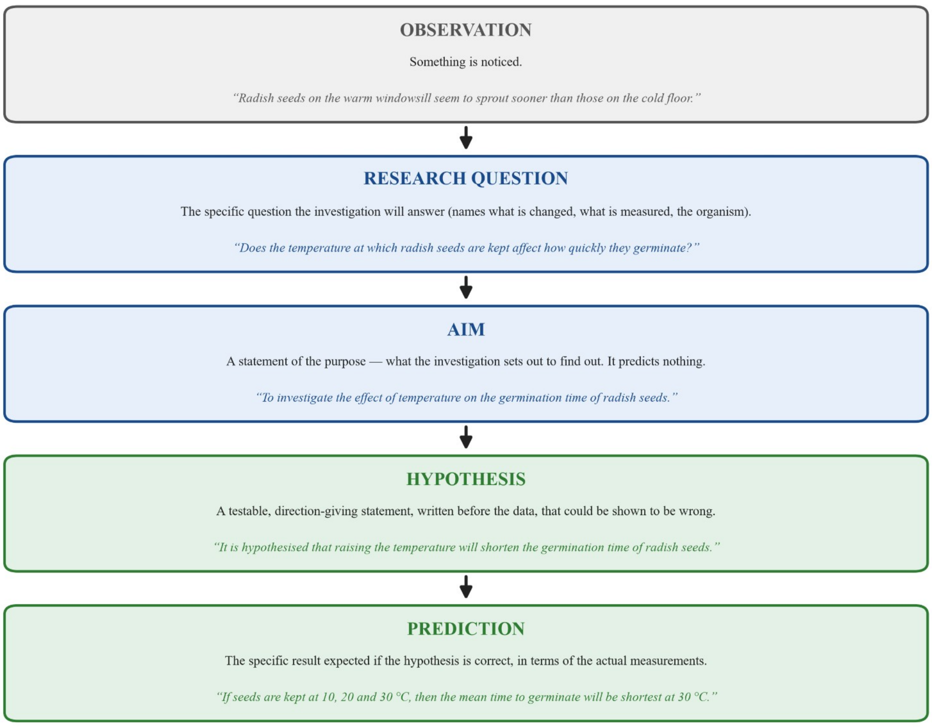
Chapter 6 Scientific investigation and primary data — 6A Designing a scientific investigation

Theory

Biology is an experimental science. Its claims are settled by **evidence**, and evidence is only ever as good as the investigation that produced it. This subtopic is about **designing** an investigation: turning something you have noticed into a question that can actually be answered, deciding what to change and what to measure, building in the comparisons and repeats that make the answer trustworthy, and meeting the safety and ethical duties that come with working on living things. (Handling and evaluating the data an investigation produces is dealt with in 6B; writing it up and communicating the findings is dealt with in 6C.)

These skills are examinable in their own right, and they are also woven through the rest of the course: you will regularly be asked to identify the variables in an unfamiliar experiment, judge whether a method is sound, or apply a safety or ethical idea to a piece of research you have never seen before.

From an observation to a testable investigation. Every investigation begins with something **noticed**. An observation on its own, though, is not a question and cannot be tested. Four separate statements turn it into an investigation, and you are expected to be able to tell them apart.



- A **research question** is the specific question the investigation will answer. It is written as a question, and a good one names the factor that will be **changed**, the thing that will be **measured**, and the **organism** involved. "Does the temperature at which radish seeds are kept affect how quickly they germinate?" is a research question; "What is germination?" is not.
- An **aim** is a statement of the **purpose** — what the investigation sets out to find out. It usually begins "To investigate…" or "To determine…" and names the same two variables. An aim **predicts nothing** and proposes nothing; it simply states the goal.
- A **hypothesis** is a **testable, proposed answer** to the research question — a statement that a change in one variable will produce a particular change in another. To be usable it must be
    - written as a **statement**, not a question,
    - written **before** the data are collected,

- about **measurable** variables, and
- able to be shown to be **wrong** by the results (this is what “testable” means).

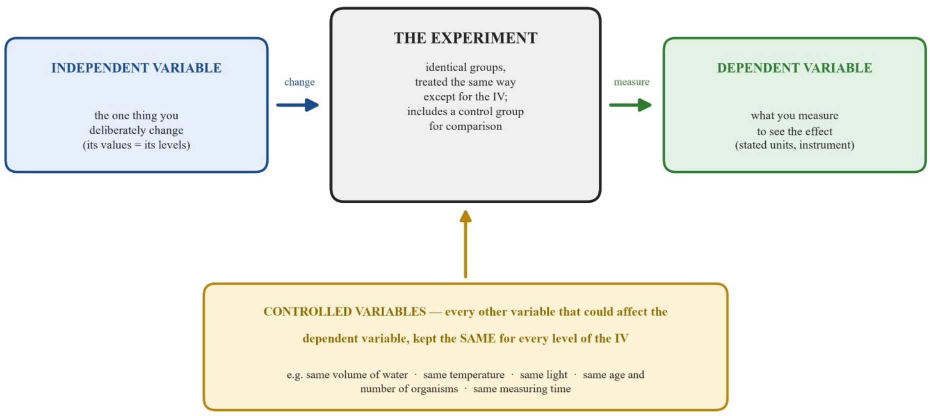
A useful house wording is: “**It is hypothesised that** [changing the first variable in a stated direction] **will** [change the second variable in a stated direction] **in** [the organism].” Notice that a hypothesis gives a **direction** (“will increase”, “will shorten”) — a vague statement such as “temperature will affect germination somehow” cannot be shown wrong, so it is not a proper hypothesis.

- A **prediction** is the **specific result expected if the hypothesis is correct**, written in terms of the actual measurements. It usually takes the form “If … then …” and names the particular values used: “If seeds are kept at 10, 20 and 30 °C, then the mean time to germinate will be shortest at 30 °C.”

Statement	What it does	Typical wording
Research question	Asks what will be found out	“Does … affect …?”
Aim	States the purpose of the investigation	“To investigate the effect of … on …”
Hypothesis	Proposes a testable, directional relationship	“It is hypothesised that increasing … will decrease …”
Prediction	States the specific result expected	“If … is set at 10, 20 and 30 °C, then …”

Two habits examiners reward: word a hypothesis so that it **could be shown to be wrong**, and, once the results are in, report that the evidence **supports** or **does not support** it — a hypothesis is never “proved”. (The wider ideas of how a hypothesis relates to a scientific **model, theory or law**, and how evidence can be *consistent with* or *challenge* a model, are developed in 6B.)

Variables. A **variable** is anything in an investigation that can take different values. A well-designed experiment sorts them into three kinds.



- The **independent variable (IV)** is the one variable the investigator **deliberately changes**. The particular values chosen are called its **levels**. The IV is the *quantity being changed* — “the temperature at which the seeds are kept” — and **not** the list of values used. Writing “10, 20 and 30 °C” as the independent variable is a common and costly error: those are its levels.
- The **dependent variable (DV)** is the variable that is **measured**, to see whether it responds to the IV. A DV must be stated precisely enough to be measured — not “growth” but “the increase in shoot height, in millimetres, after 14 days”. A DV is only useful if it genuinely **measures the effect the question is about**.
- **Controlled variables** are **every other variable that could affect the DV**, deliberately kept the **same** for every level of the IV. They are what allow a difference in the DV to be put down to the IV and to nothing else. (Watch the wording: a *controlled variable* is a variable held constant; the *control*, described next, is a group.)

A variable that is **not** kept constant and that changes along with the IV becomes a second possible explanation for the result. Once one is present, the investigation can no longer show what caused what.

The control. A **control group** (or **control condition**) is a group treated in exactly the same way as the others in every respect **except** that it does not receive the treatment being tested. Its job is to provide a **baseline for comparison**. Sometimes the control is simply the **zero level of the IV** (for example, plants watered with plain water while the others receive fertiliser); sometimes it must be a separate group given a matching but inactive treatment. The test of a good control is always the same: **is there exactly one difference between the control and the treated group?** If not, the comparison proves nothing.

Choosing a methodology. Not every question is answered by an experiment. The study design lists **nine scientific investigation methodologies**, and choosing the one that fits the question is part of the design.

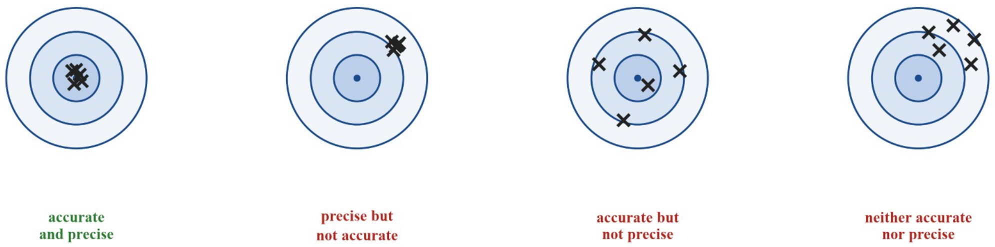
Methodology	What it involves
Controlled experiment	One variable (the IV) is deliberately changed while all others are held constant, and the DV is measured
Correlational study	Variables that have **not** been manipulated are observed and recorded, to see what association exists between them
Fieldwork	Observing, sampling and interacting with an environment beyond the laboratory (for example, by observation or by sampling with quadrats and transects)
Case study	A detailed investigation of a single real or hypothetical activity, event or problem, with all its real complexity
Classification and identification	Arranging things into groups, and recognising whether a specimen belongs to a particular group
Literature review	Collating and analysing findings and viewpoints that others have already published
Modelling	Building a physical, conceptual or mathematical representation of a system in order to understand or predict it
Simulation	Using a model to study how a system behaves when the real system cannot be used
Product, process or system development	Designing, or evaluating the design of, an object, process or system that meets a need

Only a **controlled experiment** changes the IV while holding everything else constant, which is why it is chosen whenever the question is about the **effect** of one factor on another. Where a factor **cannot be changed** — because doing so is impossible, or would be unethical — a **correlational study** or **fieldwork** is used to observe the natural association instead. It is worth remembering that an association found this way does **not** by itself prove that one factor causes the other.

Collecting good primary data. Data you generate yourself, by making your own measurements and observations, is called **primary data**. (Data taken from someone else's work — a database, a paper, a report — is **secondary data**, and is dealt with in Unit 2.) Four ideas decide how good primary data is: accuracy, precision, repeatability and reproducibility, and validity.

Accuracy and precision are different things, and the difference matters.

- **Accuracy** describes how close a measurement (or, better, the **mean** of several) is to the **true value** — the value that would be found if the quantity could be measured perfectly.
- **Precision** describes how **close repeated measurements are to one another**, whether or not they are near the true value.



× = a single reading   ● = the true value   (accuracy is judged from the mean of the set; precision is the spread)

The four targets above show every combination. Measurements can be precise (tightly grouped) yet inaccurate (grouped in the wrong place), or accurate on average yet imprecise (scattered widely around the true value). The two problems have different causes:

- A **systematic error** shifts every reading in the **same direction** by a similar amount — for example, a balance that reads 2 g high, or always starting a measurement from the wrong mark. It damages **accuracy**, and because it is not random, **repeating and averaging will not remove it**.
- A **random error** scatters readings **unpredictably, above and below** the true value — for example, slight differences in judgement or reaction time between readings. It damages **precision**, and its effect **can be reduced by taking more readings and averaging** them.

Repeatability and reproducibility both describe getting **consistent results when the measurement is done again**, but under different conditions.

- **Repeatability** means the results are close together when the **same person repeats** the measurement using the **same method and equipment**, over a short time.
- **Reproducibility** means the results are close together when a **different person, or a different laboratory or equipment**, repeats the investigation.

Results that are highly repeatable and reproducible can be trusted more, because it is unlikely the same consistent result arose by chance.

Validity ties the whole design together. An investigation is **valid** when it actually **tests the hypothesis it set out to test**. That needs three things: the **DV genuinely measures the effect** the question is about (a "firmness judged by hand" measure is less valid than a measured mass); **only the IV differs** between the groups (all other variables controlled); and a **suitable methodology** has been chosen. An investigation can be precise and repeatable and still be **invalid** if, for example, an uncontrolled variable is really responsible for the difference.

Sample size and repetition. Living things vary, so a result from a single organism, or a single reading, could easily be a one-off. Using a **larger sample** (more organisms) and **repeating** each measurement makes the result **more reliable**: repeats reduce the effect of random error and let an odd, anomalous result be spotted, and a larger sample is more likely to be **representative** of the whole group rather than of one unusual individual. Where the thing being sampled **varies from place to place** — patchy ground cover, for instance — several samples must be spread across the area before any one site can be described, or the figure recorded is simply that of whichever patch happened to be chosen. (Deciding *how* to average and analyse those repeated readings — and how to deal with an anomalous reading, or **outlier** — is developed in 6B.)

Health, safety and ethics. Because investigations use equipment, chemicals and living things, they must be planned to be **safe** and **ethical** before any data are collected.

- **Safety** starts with a **risk assessment**, written **before** any work begins: identify the **hazards** (a hot water bath, a sharp scalpel, an irritant chemical, slippery or deep water on fieldwork), judge how likely and how serious the **risk** is, and put a **control** in place to reduce it (safety glasses and care with heat and glassware, safe disposal of biological material, telling someone where you are and never working alone near water on fieldwork). For any chemical used, the risk assessment must be **informed by that chemical's safety data sheet (SDS)** — the document supplied with every substance, setting out its **hazards** and how it must be

handled, stored, used and disposed of, what protective equipment is needed, and what first aid to give. The school's **occupational health and safety** rules apply throughout.

- **Ethics** means treating people, other organisms and the environment properly. Five **ethical concepts** guide the design of an investigation:
    - **integrity** — searching honestly for understanding, and reporting **all** the results and sources — favourable or not — in a form that others can check;
    - **justice** — **fair** consideration of competing claims, **no unfair burden** on any one group, and fair sharing of, and access to, any benefit;
    - **beneficence** — a commitment to **maximising the benefits** of what is done **and minimising its risks and harms**;
    - **non-maleficence — avoiding causing harm**; where some harm cannot be avoided, making sure it is **not out of proportion to the benefit** (using the smallest number of organisms needed, and handling and releasing them with care);
    - **respect** — giving due regard to the value of living things and to people's welfare, beliefs and right to make their own choices (**informed consent** and the right to **withdraw**), and, where fieldwork is done on Country, to the knowledge and custodianship of the Traditional Owners of that land.

  (Three broader **approaches** to weighing up an ethical issue — consequences-based, duty- or rule-based, and virtues-based — are introduced when bioethical issues are studied in detail in Unit 2. Here it is enough to plan an investigation that is safe, honest and kind to the living things it involves.)

Design an investigation well and its evidence can be trusted; design it poorly — an untestable hypothesis, the wrong methodology, an uncontrolled variable, an invalid measurement, or a single unrepeated reading — and no amount of later analysis can rescue the result.

Worked examples

Example 1 — scaffolded

A student reads that caffeine is a stimulant and wonders whether it speeds up the heartbeat of a **water flea** (a small, transparent freshwater animal whose beating heart can be seen and counted under a microscope). The student can place water fleas in pond water containing different concentrations of caffeine. Write a suitable **research question**, **aim** and **hypothesis**, and identify the **independent** and **dependent** variables.

Working	Comment
The factor the student can change is the **caffeine concentration**; the thing that responds is the **heart rate**; the organism is the **water flea**.	Every design statement should name what is changed, what is measured, and the organism.
Research question: "Does the concentration of caffeine in the water affect the heart rate of water fleas?"	A research question is written as a question and names both variables.
Aim: "To investigate the effect of caffeine concentration on the heart rate of water fleas."	An aim states the purpose only — it predicts nothing.
Hypothesis: "It is hypothesised that increasing the caffeine concentration will increase the heart rate of water fleas."	A hypothesis is a statement (not a question), gives a direction, and could be shown to be wrong.
IV = the caffeine concentration (its levels are the actual concentrations used); **DV** = the heart rate, in beats per minute.	The IV is the quantity you change, not the list of values; the DV is what you measure, in stated units.

Example 2 — scaffolded

To check a ruler, a student measures the length of the **same** dried leaf five times. The leaf's true length, found with calibrated digital callipers, is **58 mm**. The ruler readings are **62, 63, 62, 63 and 62 mm**. Describe the **accuracy** and the **precision** of the ruler readings, and suggest what kind of error is present.

Working	Comment
The five readings all lie within 1 mm of each other (62–63 mm), so they are very close together.	Precision is about how close the repeated readings are to **one another**.
Readings this tightly grouped are **precise**.	State the precision judgement.
The mean reading is (62 + 63 + 62 + 63 + 62) ÷ 5 = **62.4 mm**, but the true length is 58 mm — about 4 mm too high.	Accuracy is about how close the **mean** is to the true value.
The mean is well above the true value, so the readings are **not accurate**.	State the accuracy judgement.
Every reading is wrong in the **same direction** (all too high) by a similar amount, which points to a **systematic error** — for example, not lining the leaf up with the zero mark of the ruler. Repeating and averaging would not fix it.	A one-directional, repeatable offset is a systematic error; it harms accuracy, not precision.

Example 3 — unscaffolded

A researcher wants to find out whether the amount of **shade** a rock receives is related to how much **moss** grows on it, in a forest gully. The shade a rock receives cannot be changed by the researcher. Explain which scientific methodology is most suitable and why a controlled experiment is not, state one variable that should be recorded or standardised so the comparison is fair, and describe how the moss could be measured objectively.

Because the factor of interest, the shade, **cannot be manipulated** by the researcher, this is not a question a **controlled experiment** can answer — you cannot deliberately set each rock to a chosen shade level. Instead the researcher should use a **correlational study carried out as fieldwork**: measure the shade each rock naturally receives and the moss on it, and look for an **association** between them. To make the comparison fair, a variable such as the **rock type** (or its aspect, or surface area) should be recorded or standardised, since these could also affect moss growth. The moss should be measured **objectively** rather than by eye — for example, as the **percentage of ground cover** estimated with a gridded quadrat — so the measurement is quantitative and repeatable. ∴ a correlational field study is the suitable methodology, because the factor of interest cannot be manipulated; the researcher observes the natural relationship, remembering that a correlation alone does not prove that shade *causes* the difference in moss.

Example 4 — unscaffolded

A student plans to investigate whether adding a **herbal extract** to the water changes how many **brine shrimp** eggs hatch. The extract must first be dissolved in **hot water**. Identify one **safety hazard** in the method and how to manage it, name one **ethical concept** the student should consider when working with the live brine shrimp, and explain one change that would make the results more **reliable**.

A clear **safety hazard** is the **hot water** used to dissolve the extract, which could scald the skin; this is managed by handling it carefully with heat-proof gloves, keeping the volume small, and letting it cool to room temperature before the living eggs are added. An important **ethical concept** here is **non-maleficence** — minimising harm to the living brine shrimp: the student should use only the number of eggs needed, keep the shrimp in suitable conditions, and handle and dispose of them humanely (a respect for living things). The result would be made more **reliable** by using a **larger sample and repeating** the test — hatching many eggs in several replicate containers at each concentration and averaging — rather than relying on a single container, so that random variation between individual eggs does not distort the finding. ∴ a safe, humane and repeated design gives a trustworthy answer while protecting both the student and the organisms.

Practice questions

Scaffolded

Q1. Define each of the following terms: (a) independent variable; (b) dependent variable; (c) controlled variable.

Q2. A hypothesis is a key part of an investigation's design. (a) State two features that a properly written hypothesis must have. (b) Explain why an aim is not the same as a hypothesis. (c) A student writes: "Fertiliser will change how plants grow." Rewrite this as a proper, testable hypothesis.

Q3. Repeated measurements can be described by their accuracy and their precision. (a) Define accuracy. (b) Define precision. (c) State what is meant by the **true value** of a quantity being measured.

Q4. The study design lists nine scientific investigation methodologies. (a) Name the methodology in which one variable is deliberately changed while all others are held constant. (b) Name a methodology suitable when the factor of interest cannot be changed by the investigator. (c) Name the methodology that involves building a physical or conceptual representation of a system.

Q5. Good design makes an investigation's results trustworthy. (a) Distinguish between repeatability and reproducibility. (b) State what it means for an investigation to be valid. (c) State how increasing the sample size tends to affect the reliability of a result.

Q6. A student plans to collect pond water, warm a sample of it over a flame, add a drop of a chemical stain, and examine the small organisms in it under a microscope. (a) Identify one hazard of using the chemical stain and one way to manage it. (b) Name one ethical concept the student should keep in mind when working with the living organisms collected. (c) Name the document that must inform the risk assessment for the stain, and state one thing it tells the user.

Unscaffolded

Q7. A student hypothesises that increasing the amount of salt in the soil will reduce the height of wheat seedlings. Write a suitable **prediction** for an investigation that tests this at 0, 5 and 10 grams of salt per litre, and explain how a prediction differs from a hypothesis. *(2 marks)*

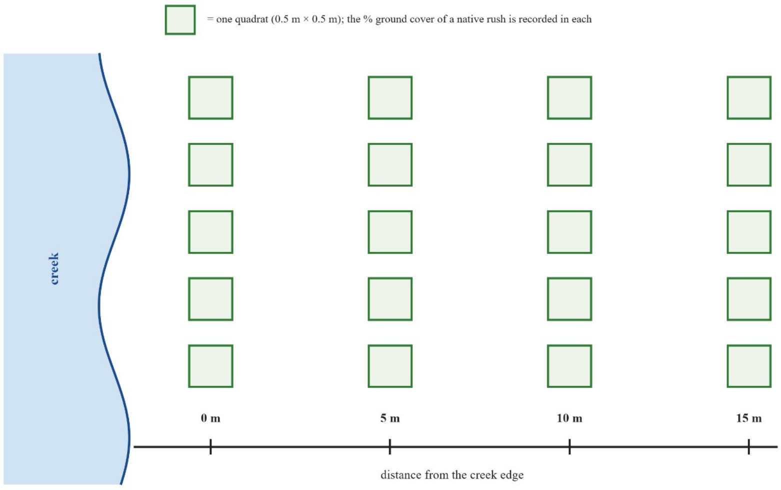
Q8. Explain why a hypothesis must be able to be shown to be wrong, using an example of a statement that could not be. *(3 marks)*

Q9. In a report, a student wrote: "The independent variable was 5 °C, 15 °C and 25 °C." The seeds were kept at each of these temperatures and the number that germinated was counted. (a) Explain why the independent variable has not been stated correctly. (b) State the independent variable correctly. (c) State what the three temperatures are properly called, and identify the dependent variable. *(3 marks)*

Q10. In a test of a new plant fertiliser, one group of plants is given the fertiliser solution while an otherwise identical group is given plain water. Explain the purpose of the plain-water group, and why the investigation would be difficult to interpret without it. *(3 marks)*

Q11. A class finds that cuttings of a garden plant grow more roots when the cut end is dipped in a rooting powder than when it is not. A class at another school follows the same written method, using its own plants, its own powder and its own equipment, and obtains the same result. (a) Name the term that describes what the second class's results demonstrate, and justify your choice. (b) Explain why this makes the original finding more trustworthy. *(3 marks)*

Q12. *(Stimulus.)* A class investigates how the ground cover of a native rush changes with distance from a creek. Quadrats are placed as shown, and the percentage of each quadrat covered by the rush is recorded.



(a) Name the scientific methodology being used.
(b) State the variable being measured and the factor it is being compared against.
(c) State one variable that should be kept the same at every distance, and why.
(d) The rush grows in patches. Explain why five quadrats are recorded at each distance rather than one. *(4 marks)*

Q13. *(Data interpretation.)* Two students each measured the length of the **same** insect specimen five times. The specimen's true length is **40.0 mm**.

Student	Readings (mm)
P	44, 40, 37, 41, 38
Q	45, 50, 44, 49, 42

(a) For each student, state whether the readings are accurate, precise, both, or neither — justifying your answer with the data.
(b) Identify the kind, or kinds, of error most likely affecting each student's readings. *(4 marks)*

Q14. Distinguish between a random error and a systematic error, and state which of the two can be reduced by repeating a measurement and averaging. *(3 marks)*

Q15. A student decides to measure "plant health" by judging the greenness of the leaves by eye. (a) Explain why this measure threatens the validity of the investigation. (b) Suggest a more valid way to measure the health of the plants, and explain why it is more valid. *(3 marks)*

Q16. Students often confuse a controlled variable with a control. (a) Distinguish between a controlled variable and a control. (b) In an experiment testing whether adding a dissolved mineral to the water increases the growth of duckweed (a small floating water plant), give one example of a controlled variable and describe a suitable control. *(3 marks)*

Q17. A student plans to investigate the effect of two minutes of exercise on the heart rate of volunteer classmates. (a) Identify one safety hazard and how it should be managed. (b) Name one ethical concept relevant to using human volunteers, and describe how the student would address it. (c) State one variable that should be controlled, and one change that would make the results more reliable. *(4 marks)*

Q18. *(Method design.)* A student sets up a sealed chamber that is dark at one end and brightly lit at the other, places ten **slaters** (small land crustaceans) in the middle, and after ten minutes counts how many are in the dark half. (a) Name the independent variable and the dependent variable. (b) Name the methodology being used. (c) Explain why the ten slaters are placed in the middle of the chamber at the start, and why the count is taken after ten minutes rather than immediately. *(4 marks)*

Q19. *(Synthesis.)* A student investigates whether the temperature of the water affects how quickly a piece of pondweed produces oxygen. The student places a piece of pondweed in water at 15 °C, 25 °C and 35 °C and, once at each temperature, counts the bubbles rising from the cut stem in one minute. (a) Write a suitable hypothesis for this investigation. (b) Identify the independent variable, the dependent variable, and two variables that should be controlled. (c) The student took only one reading at each temperature. Explain how this weakens the investigation, and state what should be done instead. (d) Counting fast-rising bubbles by eye tends to miss some when the bubbles come quickly. Explain whether this is a random or a systematic error, and how it would affect the results. *(8 marks)*

Answers

Q1. (a) The one variable the investigator deliberately changes. (b) The variable that is measured to see whether it responds to the IV. (c) A variable kept constant so that it does not also affect the DV. **Q2.** (a) Any two of: a statement (not a question); written before the data; about measurable variables; gives a direction; able to be shown wrong. (b) An aim only states the purpose and predicts nothing; a hypothesis proposes a testable, directional relationship. (c) e.g. "It is hypothesised that increasing the amount of fertiliser will increase the height of the plants." **Q3.** (a) How close a measurement (or the mean) is to the true value. (b) How close repeated measurements are to one another. (c) The value (or narrow range of values) that would be found if the quantity could be measured perfectly. **Q4.** (a) Controlled experiment. (b) Correlational study (or fieldwork). (c) Modelling. **Q5.** (a) Repeatability = consistent results when the same person repeats it with the same method and equipment; reproducibility = consistent results when a different person/equipment/lab repeats it. (b) It actually tests the hypothesis it set out to test — the DV measures the intended effect and only the IV differs. (c) It makes the result more reliable (more representative, less affected by random variation). **Q6.** (a) e.g. the stain may irritate the skin or eyes — wear gloves and safety glasses, use the smallest volume needed and wipe up any spill at once. (b) e.g. non-maleficence (avoiding harm) / respect for living things. (c) The stain's safety data sheet (SDS) — it sets out the substance's hazards and how it must be handled, stored, used and disposed of. **Q7.** e.g. "If wheat seedlings are grown in solutions containing 0, 5 and 10 grams of salt per litre, then the mean height after 14 days will be greatest at 0 and least at 10 grams per litre." A hypothesis states the general, testable relationship; a prediction states the specific result expected from this particular method, in the actual values measured. **Q8.** A hypothesis must be falsifiable — if no possible result could contradict it, testing it tells you nothing. e.g. "temperature affects growth somehow" cannot be shown wrong; "raising the temperature increases growth" can. **Q9.** (a) Those three values are the levels of the IV, not the IV itself. (b) The IV is the temperature at which the seeds are kept. (c) They are the levels (values) of the IV; the DV is the number of seeds that germinate. **Q10.** The plain-water group is the control/baseline; identical except that it gets no fertiliser, so any extra growth in the treated group can be attributed to the fertiliser and not to other factors. Without it there is nothing to compare against. **Q11.** (a) Reproducibility — the same investigation was repeated under changed conditions (a different person, laboratory, equipment and batch of plants) following the same method, and gave an agreeing result. (b) The same result is unlikely to have arisen twice by chance or from something peculiar to one class's plants, equipment or technique, so it can be attributed to the treatment itself. **Q12.** (a) Fieldwork. (b) Measured: the percentage ground cover of the rush; compared against distance from the creek. (c) e.g. quadrat size / time of year / same person judging cover — so it does not also affect the cover recorded. (d) Cover varies from patch to patch, so one quadrat might land on an unusually dense or bare patch; the mean of five is representative of that distance and shows up an odd quadrat. **Q13.** (a) P: accurate but not precise (mean 40.0 mm = true value, but readings 37–44 are widely spread); Q: neither accurate nor precise (readings spread 42–50 mm and the mean, 46.0 mm, is 6.0 mm above the true 40.0). (b) P: random error; Q: random error and a systematic error as well (wide scatter, but every reading above the true value). **Q14.** Random error scatters readings unpredictably above and below the true value (harms precision); systematic error shifts every reading the same way (harms accuracy). Repetition and averaging reduce random error only. **Q15.** (a) Greenness judged by eye is subjective and may not truly reflect health, so the DV may not measure what it claims. (b) e.g. the gain in dry mass, or the number of new leaves, over a set time — an objective, quantitative measure any observer would record the same way, so the DV genuinely measures the effect the hypothesis is about. **Q16.** (a) A controlled variable is a variable held constant so it cannot affect the DV; a control is a group/condition that receives no treatment, giving a baseline for comparison. (b) Controlled variable e.g. light/temperature/volume of water; control = duckweed grown in water with no mineral added, otherwise treated identically. **Q17.** (a) e.g. over-exertion/fainting — screen volunteers, keep exercise light, stop if unwell. (b) Respect — obtain informed consent and allow withdrawal (or non-maleficence — minimise harm). (c) Control e.g. the exercise duration/type; improve reliability by using more volunteers / repeating. **Q18.** (a) IV = the light condition (dark vs lit end); DV = the number of slaters in the dark half after ten minutes. (b) Controlled experiment. (c) Starting in the middle leaves them equidistant from both ends, so neither end is favoured and the count reflects their response, not where they were put; the ten minutes gives them time to move and settle, and the same fixed wait every trial keeps the counts comparable. **Q19.** (a) e.g. "It is hypothesised that increasing the water temperature will increase the rate at which the pondweed produces oxygen." (b) IV = water temperature; DV = number of bubbles per minute; controlled e.g. same piece/length of pondweed, same light intensity. (c) One reading cannot be checked for reliability or anomalies; repeat several times at each temperature and average. (d) Systematic error (readings consistently too low, more so when bubbling is fast); it understates the rate at higher temperatures and so understates the true effect.

Fully-worked solutions

Q1. (a) The **independent variable** is the **one variable the investigator deliberately changes** in order to see its effect. (b) The **dependent variable** is the **variable that is measured** to find out whether it responds to the change in the IV. (c) A **controlled variable** is a variable **kept constant (the same for every level of the IV)** so that it does not also affect the dependent variable and confuse the result.

Q2. (a) Any **two** of: it is a **statement**, not a question; it is written **before** the data are collected; it is about **measurable** variables; it states a **direction** (what will increase or decrease); it is **able to be shown to be wrong**. (b) An **aim** only states the **purpose** of the investigation and **predicts nothing**, whereas a **hypothesis proposes a testable, directional relationship** between the variables that the results could support or contradict. (c) A suitable rewrite: **"It is hypothesised that increasing the amount of fertiliser given to the plants will increase their height."** (This names a measurable variable and a clear direction, so it can be tested and shown wrong; "change how plants grow" cannot.)

Q3. (a) **Accuracy** is **how close a measurement, or the mean of several measurements, is to the true value**. (b) **Precision** is **how close repeated measurements are to one another** (their spread), whether or not they are near the true value. (c) The **true value** of a quantity is the value — or the narrow range of values — that **would be found if the quantity could be measured perfectly**. It is the standard against which **accuracy** is judged; in a school investigation it is usually taken from a calibrated instrument or an accepted reference value.

Q4. (a) A **controlled experiment**. (b) A **correlational study** (fieldwork is also acceptable). (c) **Modelling**.

Q5. (a) **Repeatability** means the results are close together when the **same person** repeats the measurement with the **same method and equipment**; **reproducibility** means the results are still close together when a **different person, laboratory or set of equipment** repeats the investigation. (b) An investigation is **valid** when it **actually tests the hypothesis it set out to test** — the dependent variable genuinely measures the effect in question, and only the independent variable differs between the groups (all other variables controlled). (c) Increasing the sample size makes the result **more reliable**: it is more likely to be **representative** of the whole group and less influenced by one unusual individual or by random variation.

Q6. (a) A clear hazard of the **chemical stain** is that it may **irritate the skin or eyes** (and will stain skin and clothing); it should be managed by wearing **gloves and safety glasses**, using only the **smallest volume needed**, keeping the bottle stoppered, and **wiping up any spill at once**. (b) Any one suitable concept, e.g. **non-maleficence** (avoiding harm to the living organisms — collecting only as many as are needed and returning the rest to the pond) or **respect** for living things. (c) The risk assessment must be informed by the stain's **safety data sheet (SDS)**, the document supplied with every chemical. It sets out the substance's **hazards** and the precautions required: how it must be **handled, stored, used and disposed of**, what **protective equipment** is needed, and what **first aid** to give if there is an accident. *(No mark allocation — scaffolded question.)*

Q7. A suitable **prediction**: **"If wheat seedlings are grown in solutions containing 0, 5 and 10 grams of salt per litre, then the mean height of the seedlings after 14 days will be greatest at 0 grams per litre and least at 10 grams per litre."** A **hypothesis** is the **general, testable statement** of the proposed relationship between the variables — "increasing the salt in the soil will reduce the height of wheat seedlings". A **prediction** takes that hypothesis and states the **specific result expected from this particular method**, written in terms of the **actual levels used and the actual measurement taken**, so that it can be compared directly with the results obtained. *(1 mark: a prediction in the "If … then …" form, naming the levels used and the measured outcome; 1 mark: the hypothesis states the general proposed relationship, the prediction the specific expected result for this method.)*

Q8. A hypothesis must be able to be **shown to be wrong** because that is what makes it **testable**: if **no possible result could ever contradict it**, then collecting data tells you nothing about whether it is right. For example, "temperature affects germination **somehow**" cannot be shown wrong — any result at all is "consistent" with it — so it is not a proper hypothesis. By contrast, "**raising** the temperature **shortens** germination time" **can** be contradicted (by seeds germinating no faster, or slower, when warmed), so it is genuinely testable. *(1 mark: a hypothesis must be capable of being contradicted by data / falsifiable; 1 mark: if nothing could contradict it, testing it is meaningless; 1 mark: a valid contrasting example of a non-falsifiable vs a falsifiable statement.)*

Q9. (a) The three temperatures are **not** the independent variable; they are the **particular values the variable was set to**. The independent variable is the **quantity being changed**, stated as a single thing. (b) The independent variable is the **temperature at which the seeds are kept**. (c) The three temperatures are the **levels (values) of the independent**

variable; the **dependent variable is the number of seeds that germinate**. *(1 mark: the values listed are the levels, not the IV; 1 mark: IV = the temperature at which the seeds are kept; 1 mark: the values are its levels and the DV = number germinating.)*

Q10. The plain-water group is the **control**: it is treated **identically** to the fertilised group in every way **except** that it receives **no fertiliser**, so it provides a **baseline for comparison**. By comparing the fertilised plants with this baseline, any **extra** growth can be **attributed to the fertiliser** rather than to watering, light, time or the handling that both groups received. Without the control there would be **nothing to compare the treated plants against**, so it would be impossible to tell whether the fertiliser, or simply the passing of time and normal growth, produced the result. *(1 mark: the control is identical except it gets no fertiliser; 1 mark: it is a baseline so the effect can be attributed to the fertiliser; 1 mark: without it the result cannot be interpreted / other factors could explain it.)*

Q11. (a) The second class has demonstrated **reproducibility**. Reproducibility is the closeness of the results when the same investigation is repeated under **changed conditions of measurement** — a **different person**, a **different laboratory**, **different equipment** and, here, a different batch of plants and powder — while the **method itself stays the same**. (**Repeatability** would describe the first class repeating its own measurements, with the same method and the same equipment, over a short time.) (b) It is **very unlikely that the same result would arise twice by chance**, and just as unlikely that it came from something **peculiar to one class's plants, powder, equipment or technique**. Because an independent group working separately obtained the same result, the extra rooting can be attributed to the **treatment itself** rather than to the particular set-up used, so the finding can be trusted more. *(1 mark: reproducibility; 1 mark: justified — the same method repeated by a different person, with different equipment, in a different laboratory, gave agreeing results; 1 mark: the result is unlikely to be chance or an artefact of one group's set-up, so it is more trustworthy.)*

Q12. (a) The methodology is **fieldwork**. (b) The variable being **measured** is the **percentage ground cover of the native rush** in each quadrat; it is being compared against the **distance from the creek edge**. (c) Any one suitable variable — for example the **size of the quadrat**, the **time of year**, or the **same observer judging the cover** — must be kept the **same** so that it does not itself affect the cover recorded and confuse the comparison with distance. (d) Because the rush grows in **patches**, the cover **varies from one piece of ground to the next**: a single quadrat could easily land on an unusually dense clump, or on bare ground, and the figure recorded would describe **that patch rather than that distance**. Recording **five quadrats** and taking their **mean** gives a value that is **representative** of the ground at that distance, and makes an atypical quadrat obvious rather than invisible. *(1 mark: fieldwork; 1 mark: measured = % cover of the rush, against distance from the creek; 1 mark: a valid standardised variable with reason; 1 mark: cover varies from patch to patch, so several quadrats give a representative mean for that distance.)*

Q13. (a) **Student P** is **accurate but not precise**: the readings (44, 40, 37, 41, 38 mm) are **widely spread** (37–44 mm), so they are not precise, yet their **mean is (44 + 40 + 37 + 41 + 38) ÷ 5 = 40.0 mm**, exactly the true value, so on average they are accurate. **Student Q** is **neither accurate nor precise**: the readings (45, 50, 44, 49, 42 mm) are **widely spread** (42–50 mm), so they are not precise, and their **mean is (45 + 50 + 44 + 49 + 42) ÷ 5 = 46.0 mm**, a full **6.0 mm above** the true 40.0 mm, so they are not accurate either. (b) **Student P** is most likely affected by **random error** alone — unpredictable scatter **both above and below** the true value, which is why the mean still lands on it. **Student Q**'s readings show **both kinds**: the wide scatter is **random error**, while the fact that **every** reading is above the true value shows a **systematic error** shifting the whole set in one direction. *(1 mark: P accurate but not precise, justified; 1 mark: Q neither accurate nor precise, justified; 1 mark: P = random error; 1 mark: Q = random error together with a systematic error.)*

Q14. A **random error** causes readings to **scatter unpredictably, above and below the true value**, from small uncontrolled variations (such as judgement or reaction time); it harms **precision**. A **systematic error** shifts **every reading in the same direction** by a similar amount, from a fault in the method or instrument (such as a mis-set zero); it harms **accuracy**. Only the **random error** can be reduced by **repeating a measurement and averaging**, because the scatter tends to cancel out; a systematic error stays in the average. *(1 mark: random = unpredictable scatter both sides / harms precision; 1 mark: systematic = consistent one-way offset / harms accuracy; 1 mark: repetition and averaging reduce random error only.)*

Q15. (a) Judging **greenness by eye** is **subjective** — different people would rate it differently, and greenness may **not truly reflect the plant's health** — so the dependent variable may **not actually measure what the investigation claims to measure**, which threatens **validity**. (b) A **more valid measure** of plant health would be an **objective, quantitative** one, such as the **gain in dry mass** or the **number of new leaves** produced over a set time. It is more valid because it is read from a **scale or a count** rather than judged, so **any observer would record the same value**, and because it **genuinely reflects the growth** the investigation is about — the dependent variable now measures the effect the hypothesis is about. *(1 mark: greenness-by-eye is subjective / may not reflect health, so the DV may not measure what it claims; 1 mark: a suitable objective, quantitative measure; 1 mark: why it is more valid — observer-independent and it genuinely measures the effect in question.)*

Q16. (a) A **controlled variable** is a **variable that is held constant** (kept the same for every level of the IV) so that it **cannot affect the dependent variable** and confuse the result — it is a *variable*. A **control** is a **whole group or condition** that is treated identically to the others **but receives no treatment** (or the zero level of the IV), providing the **baseline for comparison** — it is a *group*, not a variable. (b) A suitable **controlled variable** would be, for example, the **light intensity**, **temperature** or **volume of water** — kept the same for every dish; the **control** would be a dish of duckweed grown in water with **no mineral added**, otherwise treated exactly like the mineral-treated dishes, so that any extra growth can be attributed to the mineral. *(a: 1 mark — controlled variable = a variable held constant; 1 mark — control = a group/condition given no treatment, as a baseline; b: 1 mark — a valid controlled variable and a valid no-mineral control. Total = 3.)*

Q17. (a) A safety hazard is **over-exertion** — a volunteer could become dizzy or faint; it should be managed by **screening volunteers first, keeping the exercise light and brief, and stopping immediately if anyone feels unwell**. (b) A relevant ethical concept is **respect**: the student must obtain each volunteer's **informed consent** (explaining what is involved) and allow them to **withdraw at any time without penalty**. (Non-maleficence — minimising harm — is also acceptable.) (c) A variable that should be **controlled** is, for example, the **duration or type of exercise** (the same for everyone); the results could be made **more reliable** by using **more volunteers** and/or **repeating** the measurement. *(1 mark: a valid hazard + management; 1 mark: a valid ethical concept + how it is addressed; 1 mark: a valid controlled variable; 1 mark: a valid reliability improvement.)*

Q18. (a) The **independent variable** is the **light condition** (the dark end versus the lit end); the **dependent variable** is the **number of slaters found in the dark half after ten minutes**. (b) The methodology is a **controlled experiment** (the investigator sets up and controls the conditions and changes one factor). (c) The slaters are released in the **middle** so that they start **equidistant from both ends**: **neither end is favoured** at the start, so the final count reflects the animals' **response to the light** and not the position they happened to be put in. The count is taken **after ten minutes** because the slaters need **time to move and settle** into a response — a count taken immediately would record only their starting positions — and using the **same fixed waiting time in every trial** keeps the procedure **standardised**, so the counts from different trials can fairly be compared. *(1 mark: IV = light condition, DV = number in the dark half; 1 mark: controlled experiment; 1 mark: starting in the middle removes any starting-position bias; 1 mark: the fixed waiting time allows a response and standardises the trials.)*

Q19. (a) A suitable hypothesis: **"It is hypothesised that increasing the water temperature will increase the rate at which the pondweed produces oxygen (the number of bubbles per minute)."** (b) The **independent variable** is the **water temperature**; the **dependent variable** is the **number of bubbles produced per minute**; two variables that should be **controlled** are, for example, the **same piece/length of pondweed** and the **same light intensity** (also acceptable: same water, same time of counting). (c) Taking **only one reading** at each temperature means the result **cannot be checked for reliability and an anomalous reading cannot be spotted**, and random error is not reduced; instead the student should **repeat the count several times at each temperature and take the mean**. (d) Missing some fast-rising bubbles is a **systematic error**, because it makes the count **consistently too low, and more so at higher temperatures** where bubbling is fastest; this would **understate the rate at the higher temperatures** and therefore **understate the true size of the effect** of temperature. *(a: 1 mark — a testable, directional hypothesis; b: 1 mark — IV = temperature; 1 mark — DV = bubbles per minute; 1 mark — two valid controlled variables; c: 1 mark — one reading gives no check on reliability/anomalies; 1 mark — repeat and average at each temperature; d: 1 mark — systematic error, with reason it is one-directional; 1 mark — it understates the rate at high temperature / understates the effect. Total = 8.)*

Theory

Designing an investigation and collecting readings is only half of science. The other half is turning those readings into **evidence** — organising them, processing them, looking for a pattern, and deciding what the numbers actually allow you to conclude. This subtopic is about that second half: **what makes data trustworthy evidence, and how a scientist reasons from data to a conclusion.** (The design of the investigation itself — the aim, the hypothesis, the variables, and the accuracy and precision of the measuring — is dealt with in the previous subtopic; here we assume the readings have already been collected and ask what to do with them.)

Primary data and its characteristics. Primary data are data a scientist collects **first-hand**, by making their own observations or measurements during their own investigation. (Data taken instead from someone else's work — a textbook, a database, another scientist's published results — are **secondary data**, dealt with later in the course.) Primary data may be:

- **quantitative** — a **measured or counted number** with a unit, such as a height in centimetres, a time in seconds, or a count of seeds. Quantitative data can be processed with arithmetic and graphed.
- **qualitative** — a **described quality or category** that is not a number, such as a colour, a shape, "cloudy or clear", or "alive or dead". Qualitative data are recorded in words or categories.

Good primary data are **relevant** to the aim (they actually measure the effect being investigated), there are **enough** of them (repeats and a reasonable sample size), and they come from a **valid** method. Weak data cannot be rescued by clever processing afterwards.

Recording data — the logbook. Scientists record their **raw data** — the original readings, exactly as measured — in a **logbook** (a dated journal or record book), **at the time the measurement is made**. Recording as you go, rather than trusting your memory or tidying up later, means the record is **accurate and complete**: it captures every reading, the date and conditions, any unusual observation, and any change to the method. A good logbook lets the investigator (or anyone else) **check the working, spot mistakes, repeat the investigation, and trace exactly where each processed value came from.**

The logbook has a second job that matters just as much: it **authenticates** the data. To **authenticate** generated primary data is to be able to show that the data are **genuinely your own**, and were **really obtained when and how you say they were**. A dated entry written **as the measurement was taken**, kept in order and never rewritten, is the evidence for that claim — which is why **every logbook item must be dated and clearly documented**, and why a **hard-copy** logbook is preferred for assessed work: a bound, dated record is far harder to **falsify or alter** afterwards than a file that can be quietly edited. A tidy set of results copied up at home proves nothing about where the numbers came from; the logbook does. Raw data are usually then organised into a **results table**:

- the **independent variable (IV)** goes in the **left-hand column**, with its **unit in the heading**;
- the **dependent variable (DV)** readings — including each **repeat trial** — fill the next columns, again with units in the headings;
- a final column often holds the **processed value**, most commonly the **mean** of the repeats.

For example, an investigation of how the concentration of a dissolved plant food affects the growth of a small floating water plant (measured as the increase in the number of leaf-like **fronds** over ten days) might record three trials at each concentration:

Fertiliser concentration (g/L)	Trial 1	Trial 2	Trial 3	Mean increase in fronds
0	3	4	5	4
1	8	9	10	9
2	13	14	15	14
4	9	10	11	10

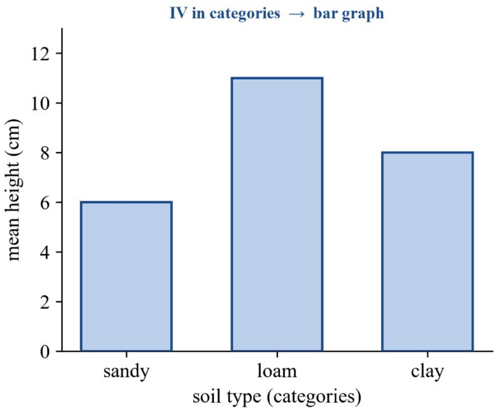
Fertiliser concentration (g/L)	Trial 1	Trial 2	Trial 3	Mean increase in fronds
8	2	3	4	3

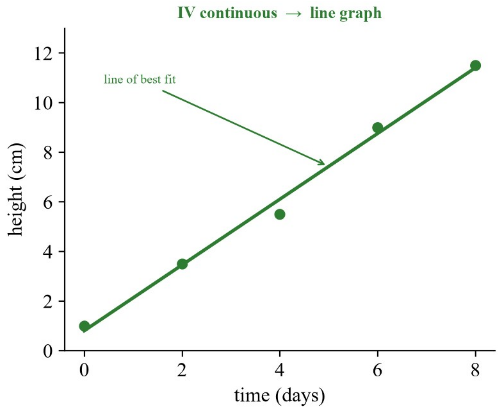
Processing quantitative data — the four calculations you need. At this level you process data using only **simple arithmetic** — no statistics. The four operations are:

- **Mean (average)** — add the repeat values and divide by the number of them. This smooths out the small variation between repeats and gives a single representative value. For the 2 g/L row above, mean = (13 + 14 + 15) ÷ 3 = 42 ÷ 3 = **14 fronds**.
- **Ratio** — a comparison of two quantities, written a : b and simplified. If one group gained a mean of 14 fronds and another gained 7, the ratio of growth is 14 : 7 = **2 : 1**.
- **Percentage** — a part expressed out of 100: percentage = (part ÷ whole) × 100. If 16 of 20 seeds germinate, that is (16 ÷ 20) × 100 = **80%**.
- **Percentage change** — how much a value has risen or fallen relative to its starting value: percentage change = (final − initial) ÷ initial × 100. From 0 to 2 g/L the mean growth rose from 4 to 14 fronds, a change of (14 − 4) ÷ 4 × 100 = **+250%** (a percentage change lets you compare changes fairly even when the starting values differ).

Displaying data — choosing the right graph. A graph reveals a pattern that a table can hide. The **independent variable always goes on the horizontal (x) axis** and the **dependent variable on the vertical (y) axis**; both axes are labelled **with units**, given a sensible even scale, and the plotted points are shown clearly. The **type** of graph depends on the **kind of IV**:

- a **bar graph** is used when the IV is in **separate categories** (for example soil type: sandy, loam, clay) — the bars do not touch, because there are no values in between;
- a **line graph** is used when the IV is a **continuous quantity** (for example time, temperature, or concentration) — a line or curve of **best fit** is drawn to show the overall trend.



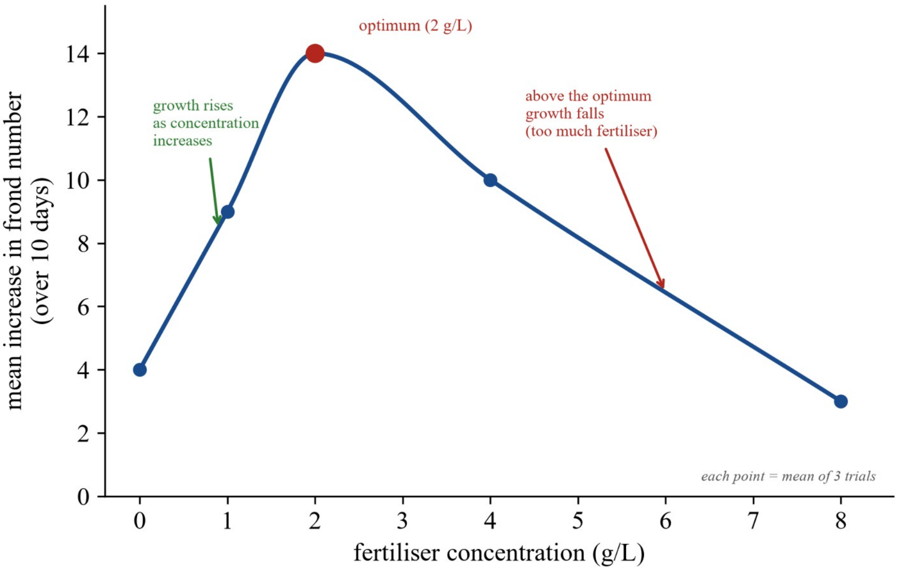


A **line of best fit** (a smooth line following the general trend, not a jagged dot-to-dot join) lets you **read values between the plotted points (interpolate)** and gives a more reliable estimate, because it averages out the small scatter of individual points rather than being pulled about by each one. Reading **beyond** the range you actually tested (**extrapolating**) is far less safe: you have **no evidence** for what the variables do outside the values you measured, and a trend that holds across the tested range may level off, reverse or stop entirely just past it.

Analysing data — patterns, trends and relationships. Once the data are graphed, you **describe the trend using directional language** and identify the **relationship** between the variables:

- a **positive relationship** — as the IV increases, the DV **increases**;
- a **negative relationship** — as the IV increases, the DV **decreases**;
- an **optimum** — the DV rises to a **maximum (peak)** at a particular IV value and then falls;
- **no relationship** — changing the IV makes **no consistent difference** to the DV.

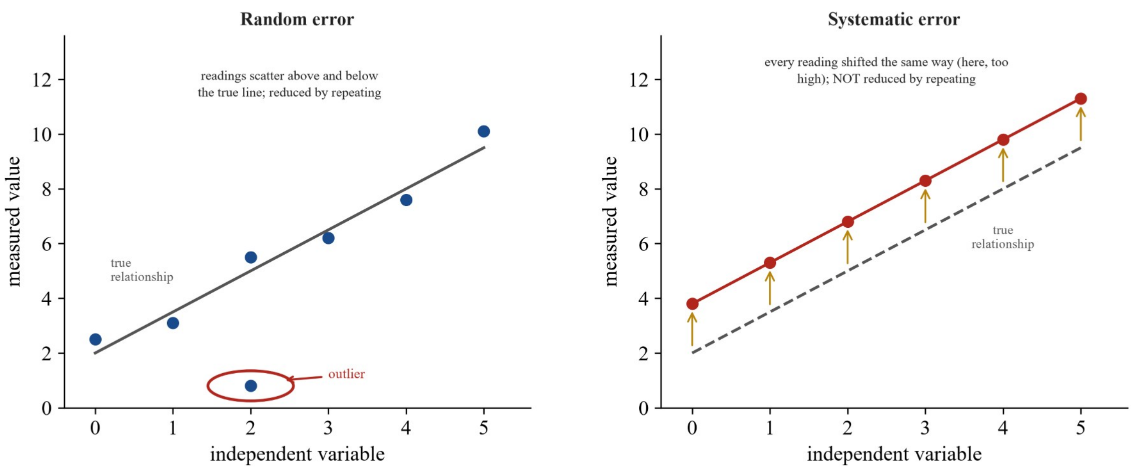
The plant-food data above show an **optimum**: as concentration rises the growth increases to a peak at **2 g/L**, then **falls** at higher concentrations (too much fertiliser harms the plant).



When you describe a trend, use words such as **increases, decreases, rises steadily, levels off, peaks**, and quote **values from the data** to support each statement. A crucial caution: **a relationship (correlation) between two variables does not by itself prove that one causes the other** — two things can rise together for a different reason. A controlled investigation is what lets you argue for cause; the graph alone shows only the association.

Sources of error. Every set of real data contains some **error** — a difference between a reading and the true value. Two kinds of **measurement error** are considered at this level, and telling them apart is essential:

- **Random error** is **unpredictable scatter**: repeated readings fall a little **above and below** the true value, differently each time (for example slight variation between individual organisms, or small differences in judging a scale). Random error is **reduced by repeating the measurement and taking a mean**, and by using a **larger sample** — the highs and lows tend to cancel out.
- **Systematic error** is a **consistent shift in the same direction** in every reading, by a similar amount (for example a balance that was not zeroed and reads 0.5 g high every time, or a habit of reading a scale from the wrong angle). A systematic error is **not reduced by repeating** — every repeat is wrong the same way — so it must be found and fixed (recalibrate the instrument, correct the technique).



A **personal error** is different again: it is a plain **mistake or miscalculation** — copying a reading into the wrong row, adding up a column wrongly, or spilling half a sample. A personal error is not a property of the measurement at all, so it is **not part of judging the quality of the data**; it is simply **eliminated by doing that part of the investigation correctly next time**. Never offer "human error" as an evaluation of your data — say which measurement error you mean, or name the mistake and fix it.

An **outlier** is a single reading that lies **well outside the pattern** of the others (the circled point above). An outlier is a **separate consideration** from random and systematic error, and it must be **further analysed and accounted for, never automatically dismissed**. So an outlier should be **identified, recorded in the logbook, and investigated** — repeating those readings is often the most useful way to examine it. Only if the investigation **traces it to a specific cause** (a mistake, or a damaged sample) may it be **excluded from the mean**, and the reason must then be **stated**; **if no such cause is found, the outlier is kept** and reported, because it may be telling you something real. All measurements also carry some **uncertainty**; at this level uncertainty is described **qualitatively** (we acknowledge readings are not perfectly exact) and is **not calculated**.

Reliability and validity of evidence. These two words describe two different strengths of evidence:

- **Reliable** evidence is **consistent** — the results agree closely when the measurement is **repeated** (by the same person, called repeatability) or **reproduced** (by others, called reproducibility). Reliability is improved by more repeats and a larger sample, which also reduce random error.
- **Valid** evidence actually **measures what it is supposed to measure** and answers the aim — the DV genuinely reflects the effect of the IV, and the other variables were controlled.

The two are independent. Data can be **reliable but not valid**: if a method measures the wrong thing, repeating it just gives the same wrong answer consistently. Reliable **and** valid evidence is what a firm conclusion needs.

Drawing an evidence-based conclusion. A **conclusion** is a statement that **answers the aim (or research question)**, is **supported by the data**, states the **relationship** found, and says whether the **hypothesis was supported or not supported**. A good conclusion **quotes evidence** ("the mean growth was greatest, 14 fronds, at 2 g/L") rather than just asserting an outcome, and it does **not claim more than the data show**. Two further ideas are often confused with the conclusion:

- an **implication** is the **wider meaning or application** of the finding — what it suggests for the real world beyond the experiment (for a grower, that "adding more fertiliser than the optimum wastes money and can harm the crop");
- a **limitation** is a **shortcoming of the investigation** (a small sample, a short time, one type of plant, an instrument that could only read to the nearest millimetre) that **restricts how confident, or how general, the conclusion can be.** Naming limitations honestly is part of good science.

Models, theories and laws — how evidence builds explanations. Evidence does not stay as isolated results; scientists use it to build and test **models, theories and laws**:

- a **model** is a **simplified representation** of a structure or process — a diagram, a physical object, or a description — used to **explain and predict**. The fluid-mosaic representation of the plasma membrane is a model. A model is useful because it makes a complex thing understandable and lets you predict what should happen, but every model is a **simplification** and has **limitations** (it leaves things out). Leaving things out is the **point** of a model, not a fault in it: a model is judged by **how well it explains and predicts**, and is used **within its known limits**.
- a **theory** is a **well-supported explanation** of some aspect of the natural world that is backed by a **large body of evidence** and has **withstood repeated testing** (for example the cell theory). In science a theory is not a guess — it is among the strongest kinds of explanation.
- a **law** is a statement that **describes a consistent pattern or relationship** observed in nature under stated conditions. A law describes **what** reliably happens, but does not by itself explain **why**.

New evidence is constantly compared with existing models and theories. Evidence that agrees with what a model predicts is said to be **consistent with** the model and **supports** it; evidence that does not fit the model's predictions is said to **challenge** the model. A single surprising result does not "prove a model wrong", but repeated, reliable evidence that challenges a model leads scientists to **refine or replace** it. This openness to revision in the light of evidence is what makes science self-correcting.

Worked examples

Example 1 — scaffolded

A student investigated how the length of time seeds are soaked affects germination. At each soaking time she set up three dishes of 20 seeds and counted how many germinated:

Soaking time (h)	Dish A	Dish B	Dish C
0	4	5	6
6	10	11	12
12	15	16	17

(a) Calculate the mean number germinating at each soaking time. (b) Express the 12 h mean as a percentage of the 20 seeds. (c) Calculate the percentage change in the mean from 0 h to 12 h, and describe the trend.

Working	Comment
0 h: (4 + 5 + 6) ÷ 3 = 15 ÷ 3 = **5**; 6 h: (10 + 11 + 12) ÷ 3 = 33 ÷ 3 = **11**; 12 h: (15 + 16 + 17) ÷ 3 = 48 ÷ 3 = **16**.	Mean = add the repeats, divide by how many. Do each row separately.
(b) percentage = (part ÷ whole) × 100 = (16 ÷ 20) × 100 = **80%**.	The "whole" is the 20 seeds in a dish, not the total across dishes.
(c) percentage change = (final − initial) ÷ initial × 100 = (16 − 5) ÷ 5 × 100 = (11 ÷ 5) × 100 = **+220%**.	Use the earliest value (0 h, mean 5) as the "initial".
The mean number germinating **increases** as soaking time increases — a **positive relationship**.	Describe the trend with directional language, referring to the processed means.

Example 2 — scaffolded

For each situation below, decide how the data should be organised, displayed or classified, and justify your choice. (a) A student records the volume of gas collected from a water plant every minute for ten minutes, and repeats the whole run three times. (b) A student compares the mean height of plants grown under red, green and blue light. (c) A student's balance was never zeroed and read 0.5 g too high for every mass she measured.

Working	Comment
(a) Set the raw data out in a **results table**: **time (min)** in the **left-hand column** with its unit in the heading; the **three repeat volumes** in the next three columns, headed with their unit (mL); and a **final column for the mean volume**.	IV first on the left, then every repeat of the DV, then the processed value. Units belong in the headings, never beside each number.
(b) Light colour is in **separate categories** (red, green, blue), so a **bar graph** is appropriate; the bars do not touch because there are no values in between.	Categorical IV → bar.
(c) Because **every** reading is shifted the **same way** by the same amount, this is a **systematic error**, not random.	A one-directional, consistent shift is the signature of systematic error.
Repeating the weighings would **not** remove it — each repeat is 0.5 g too high; the balance must be **re-zeroed (recalibrated)**.	Systematic error is not reduced by averaging; random error would be.

Example 3 — unscaffolded

An investigation aimed to find out whether increasing the number of times a plant is watered each week changes its growth. Plants were watered 1, 2, 3 or 4 times per week, all other conditions kept the same, and the mean height after four weeks was 8, 15, 22 and 12 cm respectively. Write an evidence-based conclusion for this investigation, and explain how a conclusion differs from an implication.

The data show that growth **increased** as watering rose from 1 to 3 times per week (mean height rising from 8 cm to a maximum of 22 cm at 3 times per week), but then **decreased** at 4 times per week (12 cm) — so there is an **optimum watering frequency of about 3 times per week**, rather than a simple "more is better" relationship. A valid

conclusion answers the aim using this evidence: *the frequency of watering does affect growth, with growth greatest at three waterings per week and lower at both fewer and more waterings.* An **implication** is the wider, real-world meaning of that finding — for example, that a gardener should water this plant about three times a week and that over-watering wastes water and can reduce growth. The conclusion states **what the data show**; the implication states **what that means for the world beyond the experiment.** ∴ the conclusion reports the optimum relationship found in the data, while the implication applies it to practice.

Example 4 — unscaffolded

Distinguish between a scientific hypothesis, a scientific model, a scientific theory and a scientific law, giving a biological example of each.

A **hypothesis** is a **tentative, testable and falsifiable statement**, proposed **before** the data are collected, predicting how the variables will be related — for example, *if the light intensity reaching a water plant is increased, the rate at which it releases oxygen will increase*. A **model** is a **simplified representation** of a structure or process — a diagram, a physical object or a description — used in place of the real thing, which is often too small or too complex to observe directly; the fluid-mosaic representation of the plasma membrane is a model. A **theory** is a **well-supported explanation** of an aspect of the natural world, backed by a **large body of evidence** and surviving **repeated testing** — the **cell theory** is one. It is far stronger than a hypothesis, and not a mere guess. A **law** is a statement that **describes a consistent, observed pattern or relationship** in nature under stated conditions; Mendel's **law of segregation** — that the two alleles of a gene separate so that a gamete receives only one of them — describes **what** reliably happens, but not **why**, and it took the discovery of meiosis for a theory to supply the explanation. ∴ the four differ in the job each one does: a **hypothesis predicts**, a **model represents**, a **theory explains**, and a **law describes**.

Practice questions

Scaffolded

Q1. Data can be described in several ways. (a) Define the term primary data. (b) Distinguish between quantitative and qualitative data. (c) State one thing, besides the reading itself, that must be recorded with every logbook entry.

Q2. A student examined a stained root-tip squash under a microscope. In each of three fields of view she counted how many of the 50 cells present were undergoing mitosis: 8, 10 and 12. (a) Calculate the mean number of dividing cells per field of view. (b) Express the mean as a percentage of the 50 cells in a field of view. (c) Using the mean, write the ratio of dividing to non-dividing cells in its simplest form.

Q3. A results graph must be drawn correctly. (a) State whether a bar graph or a line graph is appropriate when the independent variable is a continuous quantity such as temperature, and give a reason. (b) State which axis the independent variable is plotted on. (c) A student joins her plotted points with a jagged dot-to-dot line. State the better practice for showing the trend, and explain why it gives a more reliable estimate of a value between two points.

Q4. Measurement error comes in two kinds. (a) Define random error. (b) Define systematic error. (c) Explain why repeating readings and taking a mean reduces the effect of random error but not of systematic error.

Q5. As the concentration of a dissolved nutrient was increased from 0 to 5 g/L, the mean growth of an alga rose steadily; above 5 g/L the mean growth fell. (a) Describe the relationship between nutrient concentration and growth, using directional language. (b) State the concentration that appears to be the optimum. (c) A student concludes "more nutrient always causes more growth". State one reason this conclusion is not supported by the data.

Q6. Scientists reason from data to a conclusion. (a) State two things a valid evidence-based conclusion must do. (b) A student finds that plants given more light grew taller, and concludes that the extra light *caused* the extra growth. State one thing the investigation must have done before such a causal claim is justified. (c) Define a limitation of an investigation.

Unscaffolded

Q7. Distinguish between primary data and secondary data, and give one example of each in a biological investigation. *(2 marks)*

Q8. Explain why a scientist records each raw reading in a dated logbook at the time it is measured, rather than writing the results up from memory afterwards. Give two reasons, one of which must refer to the authentication of the data. *(2 marks)*

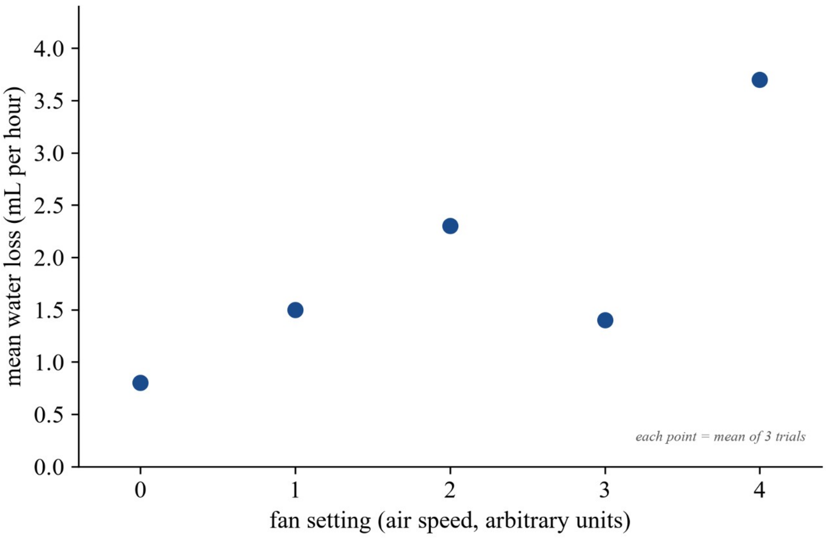
Q9. *(Data interpretation.)* A student counted the bubbles of gas released each minute by a water plant placed at different distances from a lamp, taking three readings at each distance:

Distance from lamp (cm)	Trial 1	Trial 2	Trial 3
10	58	60	62
20	28	30	32
30	18	20	22
40	13	15	17

(a) Calculate the mean number of bubbles per minute at each distance.
(b) Describe the trend shown by the means, using directional language.
(c) The student wants to predict the mean number of bubbles at 100 cm from the lamp. Suggest one reason these data should not be used to make that prediction. *(4 marks)*

Q10. For each situation, state whether the error described is a random error, a systematic error, or a personal error (a mistake). (a) Copying her readings up, a student wrote 3.5 mL in the results table for a reading her logbook records as 3.9 mL. (b) A student sometimes started the stopwatch a fraction early and sometimes a fraction late. (c) A ruler with a worn-down end meant every length was read about 1 mm short. *(3 marks)*

Q11. *(Data interpretation.)* The graph shows the mean rate of water loss from a leafy shoot at five fan settings; each point is the mean of three trials.



(a) Describe the overall trend shown by the data.
(b) One point does not fit the trend. Identify it, and state what the student should do about it.
(c) The student suggests the point is evidence of a systematic error in her method. Explain why a systematic error cannot account for it. *(4 marks)*

Q12. A student measured the height of a growing plant five times; her five readings were all within 1 mm of one another. However, each time she measured from the bottom of the pot to the top of the plant, so the pot's height was included in every reading. (a) State whether her data are reliable, and justify your answer. (b) State whether her data are valid, and justify your answer. (c) Explain how data can be reliable yet still fail to support a valid conclusion. *(4 marks)*

Q13. An investigation aimed to find out whether increasing soil nitrogen increases the leaf area of a crop. The hypothesis was that more nitrogen would give larger leaves. Across all plots, the mean leaf area rose from 18 cm^2 at low nitrogen to 34 cm^2 at high nitrogen. (a) Write a valid evidence-based conclusion for this investigation. (b) State whether the hypothesis was supported, with reference to the data. (c) State one implication of this finding for a farmer. *(4 marks)*

Q14. The fluid-mosaic model is used to represent the plasma membrane. (a) State one thing a model like this is useful for, and one limitation of using a model. (b) A student says: “The fluid-mosaic model leaves things out, so it is not good science.” Explain why this judgement is wrong. *(4 marks)*

Q15. A model predicts that the growth rate of a water plant increases as light intensity increases, up to a maximum, and then stays constant. (a) A student’s data show growth rising and then levelling off, exactly as the model predicts. State whether these data are consistent with, or challenge, the model. (b) A second student finds that at very high light intensity the growth rate falls sharply. Explain what this second result means for the model. *(3 marks)*

Q16. A student tested one seed at each of four temperatures, found the seed at the warmest temperature germinated first, and concluded that higher temperature always speeds up germination. (a) Explain why testing only one seed per temperature makes this conclusion unreliable. (b) State one change that would improve the reliability of the evidence. *(3 marks)*

Q17. *(Data interpretation.)* The table shows the mean diameter of a bacterial colony (the mean of five agar plates) grown at four different pH values.

pH of the growth medium	Mean colony diameter (mm)
5	10
6	20
7	25
8	14

(a) State the pH that gave the greatest mean colony diameter.
(b) Calculate the percentage increase in mean colony diameter from pH 5 to pH 7.
(c) Suggest why the mean colony diameter at pH 8 is lower than at pH 7. *(4 marks)*

Q18. *(Synthesis.)* A student investigated whether a rooting powder affects how fast plant cuttings grow roots. She prepared cuttings with the powder and cuttings without it, kept all other conditions the same, and after 14 days measured the root length of five cuttings from each group, recording every step in a logbook. Her logbook records nothing unusual about any of the ten cuttings, and she checked and repeated every measurement.

Group	Root length of each measured cutting (mm)
With powder	41, 44, 43, 12, 45
Without powder	22, 20, 24, 21, 23

(a) Calculate the mean root length for the “without powder” group.
(b) One reading in the “with powder” group is an outlier. Identify it, and calculate the mean of the “with powder” group both including and excluding that reading.
(c) State, with a reason, whether the outlier should be excluded when the two groups are compared.
(d) Using the means you judge most valid, write an evidence-based conclusion about whether the rooting powder increased root growth.
(e) State one limitation of this investigation other than the number of cuttings measured, and one way that limitation could be addressed. *(8 marks)*

Answers

Q1. (a) Data collected first-hand by the investigator during their own investigation. (b) Quantitative = measured/counted numbers with units; qualitative = described qualities or categories, not numbers. (c) e.g. the date (also acceptable: the time, the conditions, the units, or any change made to the method). **Q2.** (a) 10. (b) 20%. (c) 1 : 4. **Q3.** (a) A line graph, because the IV is continuous (has values in between). (b) The horizontal (x) axis. (c) Draw a line/curve of best fit; it averages out the scatter of individual points, so a value read between points is more reliable than one taken from a jagged dot-to-dot line. **Q4.** (a) Unpredictable scatter of readings above and below the true value, differing each time. (b) A consistent error shifting every reading the same way by a similar amount. (c) Random errors partly cancel when averaged, so repeats reduce them; a systematic error shifts every repeat the same way, so averaging cannot remove it. **Q5.** (a) As concentration increases up to 5 g/L, mean growth increases; above 5 g/L it decreases. (b) About 5 g/L. (c) Above 5 g/L growth fell, so it is not true that more nutrient always gives more growth (the relationship is not simply positive / there is an optimum). **Q6.** (a) Answer the aim and be supported by the data (state the relationship / whether the hypothesis was supported). (b) It must have controlled all the other variables, so that light was the only thing that differed between the groups (otherwise the result shows only a correlation). (c) A shortcoming of the investigation that limits confidence in, or the generality of, the conclusion. **Q7.** Primary = collected first-hand by the investigator (e.g. heights you measure yourself); secondary = obtained from others' work (e.g. figures from a published database or textbook). **Q8.** So the record is accurate and complete (no reliance on memory); and so the dated, on-the-spot entries authenticate the data as genuinely the investigator's own, obtained when and how claimed, which guards against falsification or later alteration. **Q9.** (a) 60, 30, 20, 15. (b) As distance increases, the mean number of bubbles per minute decreases (a negative relationship), and the decrease gets smaller / levels off. (c) 100 cm lies well outside the range tested (10–40 cm), so it would be extrapolating — there is no evidence for what the plant does beyond 40 cm. **Q10.** (a) Personal error (a mistake). (b) Random. (c) Systematic. **Q11.** (a) Overall, as the fan setting (air speed) increases, the mean water loss increases. (b) The point at fan setting 3 (about 1.4 mL/h) is anomalous — it is lower than its neighbours; the student should investigate it and repeat those trials (and note it in the logbook), not simply delete it. (c) A systematic error shifts every reading in the same direction by a similar amount, so all five points would be displaced together and the trend would keep its shape — it could not move one point alone. **Q12.** (a) Reliable — the repeats agree closely (within 1 mm). (b) Not valid — she measured the plant plus the pot, so the DV does not measure only the plant's height. (c) Repeating a method that measures the wrong thing just gives the same wrong value consistently — reliable but not valid. **Q13.** (a) Increasing soil nitrogen increased the mean leaf area (from 18 to 34 cm^2), so higher nitrogen is associated with larger leaves. (b) Supported — leaf area rose as nitrogen rose, as predicted. (c) e.g. adding nitrogen fertiliser could be used to increase leaf area/crop yield. **Q14.** (a) Useful: makes a complex structure understandable / lets you predict behaviour; limitation: it is a simplification and leaves things out. (b) Simplifying is the point of a model, not a fault — a model is judged by how well it explains observations and predicts new ones, and it is used within its known limits; leaving detail out is what makes the membrane understandable at all. **Q15.** (a) Consistent with the model. (b) It challenges the model (the model predicts a constant rate, not a fall), so the model may need to be refined/revised to include a decline at very high light. **Q16.** (a) A single seed cannot separate the effect of temperature from natural variation between individual seeds, and there is no way to spot an anomaly. (b) Test many seeds at each temperature and use the mean (repeat the trials). **Q17.** (a) pH 7. (b) 150%. (c) e.g. pH 8 is beyond the optimum pH for this bacterium, so conditions further from the optimum slow its growth and the colony is smaller. **Q18.** (a) 22 mm. (b) Outlier = 12 mm; mean including = 37 mm, mean excluding = 43.25 mm. (c) No — it must be kept. It was investigated and the logbook records no cause for it, and an outlier is not dismissed just because it is inconvenient; so the comparison uses 37 mm. (d) The powder group had a mean of 37 mm against 22 mm without powder — 15 mm more, about 1.7 times the untreated length — so the evidence supports that the rooting powder increased root growth. (e) e.g. limitation: only one type of cutting/plant was used, so the finding cannot be generalised; improvement: repeat with other species (or: root length was measured only at 14 days — measure at several times).

Fully-worked solutions

Q1. (a) **Primary data** are data the investigator collects **first-hand**, by making their own observations or measurements during their own investigation. (b) **Quantitative** data are **measured or counted numbers** with units (such as a height in cm or a count of seeds); **qualitative** data are **described qualities or categories** that are not numbers (such as colour or "cloudy/clear"). (c) Any one: the **date** (every logbook item must be dated); also acceptable — the **time**, the **conditions**, the **units**, or **any change made to the method**.

Q2. (a) Mean = (8 + 10 + 12) ÷ 3 = 30 ÷ 3 = **10 dividing cells** per field of view. (b) Percentage = (10 ÷ 50) × 100 = **20%**. (c) Of the 50 cells, the mean 10 were dividing, so 50 − 10 = 40 were not, giving dividing : not dividing = 10 : 40 = **1 : 4**.

Q3. (a) A **line graph**, because the independent variable (temperature) is **continuous** — it can take any value in between, and a line shows the trend across that continuous range. (b) The **horizontal (x) axis**. (c) She should draw a **line (or curve) of best fit** following the general trend. A line of best fit **averages out the random scatter** of the individual points, so a value read from it between two plotted points is a **more reliable estimate** than one read from a jagged dot-to-dot line, which is pulled about by the error in each single point.

Q4. (a) A **random error** is an **unpredictable variation** that makes repeated readings fall a little **above and below** the true value, **differently each time**. (b) A **systematic error** is a **consistent error** that shifts **every reading in the same direction** by a similar amount. (c) When readings are **averaged**, random errors above and below the true value **partly cancel out**, so repeating and taking a mean **reduces** their effect. A systematic error shifts **every** repeat the **same way**, so the mean is shifted too — averaging **cannot** remove it; it must be found and corrected.

Q5. (a) As the nutrient concentration **increases up to 5 g/L**, the mean growth **increases**; **above 5 g/L**, the mean growth **decreases**. (b) About **5 g/L** (the concentration giving the greatest growth). (c) Above 5 g/L the growth **fell**, so "more nutrient always causes more growth" is wrong — the relationship is **not simply positive**; there is an **optimum**, beyond which more nutrient reduces growth.

Q6. (a) A valid conclusion must **answer the aim/research question** and be **supported by (based on) the data** — stating the relationship found and whether the hypothesis was supported. (b) The investigation must have **controlled every other variable**, so that the **amount of light was the only thing that differed** between the groups. Without that, the taller plants and the extra light are only **correlated**, and some other difference could be the real cause. (c) A **limitation** is a **shortcoming of the investigation** (for example a small sample, short duration or a coarse instrument) that **reduces confidence in, or restricts the generality of, the conclusion**.

Q7. Primary data are collected **first-hand** by the investigator during their own investigation — for example, plant heights the student measures themselves with a ruler. **Secondary data** are obtained **from someone else's work** — for example, rainfall figures taken from a published weather database or a textbook. *(1 mark: primary = first-hand vs secondary = from others; 1 mark: one valid example of each.)*

Q8. Recording each reading in the logbook **at the time it is measured** means the record is **accurate and complete** — it does not rely on memory, which could forget or muddle values, and every raw reading, including any **unusual or anomalous** one, is kept so it can be checked (first reason). Second, the **dated, on-the-spot entries authenticate the data**: they are the evidence that the readings are **genuinely the investigator's own** and were **obtained when and how they claim**, so the results cannot later be **falsified or altered** to suit the expected answer. Results written up afterwards prove nothing about where the numbers came from. *(1 mark: accuracy/completeness — not relying on memory; 1 mark: authentication — a dated contemporaneous record shows the data are the investigator's own and guards against falsification/alteration.)*

Q9. (a) Means: 10 cm → (58 + 60 + 62) ÷ 3 = **60**; 20 cm → (28 + 30 + 32) ÷ 3 = **30**; 30 cm → (18 + 20 + 22) ÷ 3 = **20**; 40 cm → (13 + 15 + 17) ÷ 3 = **15** bubbles per minute. (b) As the distance from the lamp **increases**, the mean number of bubbles per minute **decreases** (a **negative relationship**), and the **rate of decrease gets smaller** — the values level off at greater distances. (c) The readings only cover **10 cm to 40 cm**, so a value at **100 cm** would have to be **extrapolated** — read well outside the range actually tested. There is **no evidence** for what the plant does past 40 cm: the trend is already levelling off and could flatten completely once the light is too dim to make any difference. *(1 mark: all four means correct; 1 mark: negative direction stated; 1 mark: notes the decrease levels off / gets smaller; 1 mark: 100 cm is outside the tested range — extrapolation is not supported by the data.)*

Q10. (a) **Personal error (a mistake)** — the instrument was read correctly and the logbook holds the true value; the wrong number was simply copied across. It is put right by **correcting the transcription**, and it is not part of judging the quality of the measurements. (b) **Random** — the mis-timing is unpredictable and happens in both directions (sometimes early, sometimes late). (c) **Systematic** — the worn ruler makes every length read short by a similar amount, in the same direction. *(1 mark each, 3 marks total.)*

Q11. (a) **Overall, as the fan setting (air speed) increases, the mean water loss increases** — the points rise from about 0.8 mL/h at setting 0 to about 3.7 mL/h at setting 4. (b) The point at **fan setting 3** (about **1.4 mL/h**) is the

anomaly/outlier — it is **lower than the points on either side**, breaking the rising trend. The student should **investigate it and repeat those trials at setting 3**, recording what she finds in the logbook; an outlier must be **analysed and accounted for, not simply deleted** because it spoils the trend. (c) A **systematic error shifts every reading in the same direction by a similar amount**, so it would displace **all five points together** and the trend would keep its shape. Here only **one** point is out of line while the other four rise steadily, so the cause must be **specific to that setting** — it cannot be a systematic error. *(1 mark: increasing trend; 1 mark: identifies setting 3 as the anomaly; 1 mark: says to investigate/repeat it rather than discard it; 1 mark: a systematic error would move every point, not one.)*

Q12. (a) Her data are **reliable**, because the five repeat readings **agree closely** (all within 1 mm of one another) — repeating gives a consistent result. (b) Her data are **not valid**, because she measured the **plant plus the pot**, so the reading does not measure **only the plant's height** — the dependent variable does not measure what it is supposed to. (c) Because **reliability and validity are separate strengths**: repeating a method that measures the **wrong thing** simply gives the **same wrong value consistently**, so the data can be reliable yet still **cannot support a valid conclusion** about the plant's true height. *(a: 1 mark — reliable, because the repeats agree closely; b: 1 mark — not valid, because the pot is included so it measures the wrong thing; c: 2 marks — reliability and validity are independent, so consistently repeating an invalid method just gives the same wrong answer.)*

Q13. (a) **Conclusion:** increasing soil nitrogen **increased the mean leaf area** of the crop — the mean rose from **18** cm^2 at low nitrogen to **34** cm^2 at high nitrogen — so a **higher nitrogen level is associated with a larger leaf area**. (b) The hypothesis (more nitrogen → larger leaves) was **supported**, because the leaf area **increased** as nitrogen increased, as predicted. (c) Any one implication: a farmer could **add nitrogen fertiliser to increase leaf area (and potentially yield)**; or, more nitrogen means more leaf growth, which may raise crop production. *(a: 2 marks — states the positive relationship AND quotes the 18 → 34* cm^2 *data; b: 1 mark — supported, referring to the data; c: 1 mark — a sensible real-world implication.)*

Q14. (a) A model like the fluid-mosaic model is **useful** because it makes a complex structure **understandable** and lets you **predict** how the membrane behaves; its **limitation** is that it is a **simplification** — it leaves out detail and cannot represent everything exactly. (b) The judgement confuses a **deliberate simplification with a fault**. A model is not meant to be a complete copy of the real thing — leaving detail out is precisely what makes a structure too small to see **understandable and usable**. A model is judged by **how well it explains observations and predicts new ones**, and scientists work **within its known limits**; the fluid-mosaic model does that job well, which is why it is used. *(a: 1 mark — a use (understanding/prediction); 1 mark — a limitation (a simplification that leaves things out); b: 2 marks — simplification is the purpose of a model, not a fault; a model is judged by how well it explains and predicts, and is used within its known limits.)*

Q15. (a) These data are **consistent with** the model — they show exactly the rise-then-level-off pattern the model predicts, so they **support** it. (b) The second result **challenges** the model: the model predicts the rate stays **constant** at high light, but the data show it **falls sharply**, which **does not fit** the prediction. If this result is **repeated and reliable**, scientists would need to **refine or revise the model** so that it accounts for a decline at very high light intensity. *(a: 1 mark — consistent with/supports; b: 1 mark — it challenges the model because a fall is not the predicted constant rate; 1 mark — reliable challenging evidence leads to the model being refined/revised.)*

Q16. (a) With **only one seed** at each temperature, the result could be due to the **natural variation between individual seeds** rather than the temperature — a single fast seed might simply have been a vigorous individual. There are **no repeats to average** and **no way to spot an anomaly**, so the evidence is **unreliable** and the conclusion is not justified. (b) **Test many seeds at each temperature and use the mean** (repeat the trials), so that individual variation is averaged out and the result is repeatable. *(a: 2 marks — one seed cannot separate temperature from individual variation; no repeats/no way to spot an anomaly; b: 1 mark — use many seeds per temperature and average / repeat.)*

Q17. (a) **pH 7** gave the greatest mean colony diameter (25 mm). (b) Percentage increase = (final − initial) ÷ initial × 100 = (25 − 10) ÷ 10 × 100 = (15 ÷ 10) × 100 = **150%**. (c) **pH 7 is the optimum** pH for this bacterium; at **pH 8** the medium is further from that optimum, so the bacterium grows more slowly and the colony is smaller — the mean diameter falls beyond the optimum even though the pH has continued to rise. *(a: 1 mark — pH 7; b: 2 marks — correct method and answer 150%; c: 1 mark — a sensible reason for the fall beyond the optimum.)*

Q18. (a) "Without powder" mean = (22 + 20 + 24 + 21 + 23) ÷ 5 = 110 ÷ 5 = **22 mm**. (b) The outlier is **12 mm** (far below the other four readings, which are 41–45 mm). Mean **including** the outlier = (41 + 44 + 43 + 12 + 45) ÷ 5 = 185

÷ 5 = **37 mm**; mean **excluding** it = (41 + 44 + 43 + 45) ÷ 4 = 173 ÷ 4 = **43.25 mm**. (c) **No — it should be kept**, so the valid "with powder" mean is **37 mm**. An outlier may only be set aside if investigating it **traces it to a specific cause**, such as a mistake or a damaged cutting, and the reason is then stated. Here the outlier **was** investigated — the logbook records **nothing unusual** about that cutting and the measurements were checked and repeated — so **no cause has been found**, and an outlier is **never dismissed simply because it is inconvenient**. The 12 mm cutting may be telling us something real: that the powder does not work on every cutting. Dropping it would flatter the result. (d) Using the valid means — **37 mm with powder** versus **22 mm without** — the treated cuttings grew a mean of **15 mm more**, about **1.7 times** the root length of the untreated cuttings, so the evidence **supports the claim that the rooting powder increased root growth**. (The claim should be made carefully: with only five cuttings per group, one low reading moves the mean a long way.) (e) Any one limitation with a matching improvement — for example: only **one type of cutting/plant** was used (limitation), so the investigation should be **repeated with other species** before the finding is generalised; or root length was measured **only once, at 14 days**, so nothing is known about the rate of growth or about what happens later — **measure at several times** across the fortnight. *(a: 1 mark — 22 mm; b: 2 marks — identifies 12 mm as the outlier and gives both means, 37 mm and 43.25 mm; c: 1 mark — not excluded, because investigation found no cause and outliers are not automatically dismissed; d: 2 marks — quotes the two valid means, 37 mm and 22 mm, and concludes the powder increased root growth; e: 2 marks — one valid limitation other than sample size, and one matching improvement.)*

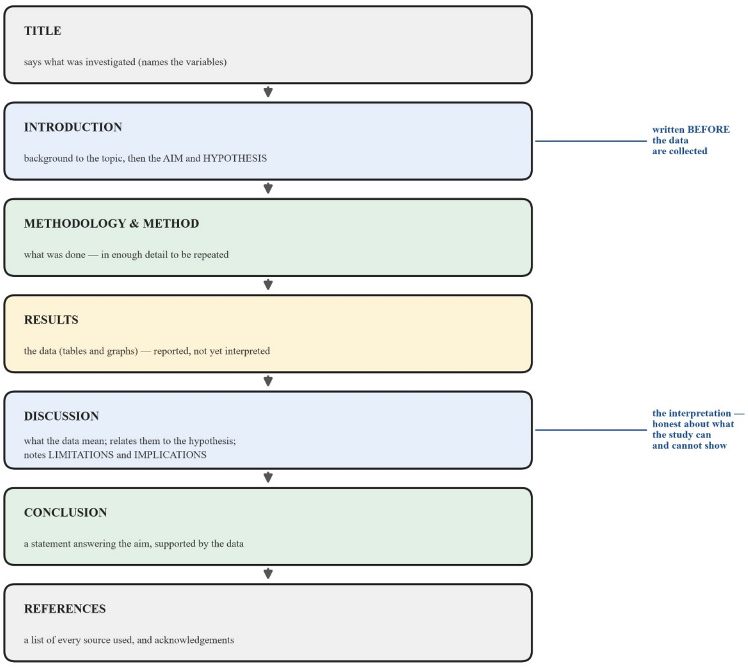
Theory

Science is not finished when the last reading is written down. A result that stays in one person's logbook changes nothing; it becomes part of science only when it is **communicated** — set out clearly and honestly so that other people can read it, judge it, trust it, repeat it and build on it. This subtopic is about that final step: **the conventions scientists follow when they report an investigation, and how to present its findings truthfully to an audience.** (Designing the investigation was 6A; turning the readings into evidence — processing, graphing, drawing a conclusion — was 6B. Here we assume the investigation is done and the conclusion reached, and ask how to communicate it well.)

Like the design and analysis skills, these communication skills are examinable in their own right, and you will meet them again in Unit 2, where you communicate a research task on a bioethical issue.

Why scientists communicate to a shared standard. Other scientists can only trust a finding if they can see exactly what was done and what was found. Reporting to an agreed set of **conventions** — a standard structure, standard language, standard ways of showing data, and standard referencing — means any reader can follow the work, check it for mistakes, and **repeat it** to see whether they get the same result. Communicating clearly is therefore not a presentation "extra"; it is part of how science tests and corrects itself.

The scientific report and its sections. The main way an investigation is written up is a **scientific report**, set out in a fixed order of **sections**, each with its own job. Writing the right material in the right section is a convention every reader expects.



- the **title** says, briefly, what was investigated — a good title names the variables (for example, "The effect of water temperature on the heart rate of water fleas");
- the **introduction** gives the background to the topic and then states the **aim** and the **hypothesis** (both written *before* the data are collected — see 6A);
- the **methodology and method** describe *what was done* — the methodology chosen and the step-by-step method — in **enough detail that another person could repeat the investigation exactly**;
- the **results** present the **data** — organised tables and graphs — **reported but not yet interpreted** (the numbers and trends, without opinion about what they mean);

- the **discussion** is where the data are **interpreted**: what the results mean, how they relate to the hypothesis (supported or not supported), the **limitations** of the investigation, and the wider **implications** of the finding (the reasoning behind these is developed in 6B);
- the **conclusion** is a short statement that **answers the aim**, supported by the data;
- the **references** list every source used, together with any **acknowledgements** of help.

Keeping **results separate from discussion** is one of the most important conventions: the results section reports *what happened*, and the discussion argues *what it means*. Mixing them makes it hard for a reader to tell an observation from an interpretation.

The scientific poster. The same investigation can instead be communicated as a **scientific poster** — a single large sheet designed to be read quickly, often while standing in front of it. A poster carries the **same sections** as a report but in a much more **condensed, visual** form: a clear title, short blocks of text under headings, and **graphs, diagrams and images doing most of the work**, with only the key points in words. An effective poster has a clear title, a logical layout that guides the eye, readable text that is not overcrowded, and visuals that can be understood at a glance.

Scientific language. Scientific writing follows conventions that keep it **clear, objective and precise**:

- it is **objective and impersonal** — it reports what was done and found rather than the writer's feelings, and usually avoids "I/we" and emotive words ("the amazing result"). It is normally written in the **past tense** (the investigation has already happened);
- it uses **tentative, honest wording about how strongly the evidence stands**: results **support** or **do not support** a hypothesis — they never "**prove**" it, because a later investigation might always find otherwise;
- it uses **precise scientific terminology** rather than vague everyday words, and every **abbreviation is written out in full the first time it is used** (for example, "adenosine triphosphate (ATP)"), so a reader is never left guessing.

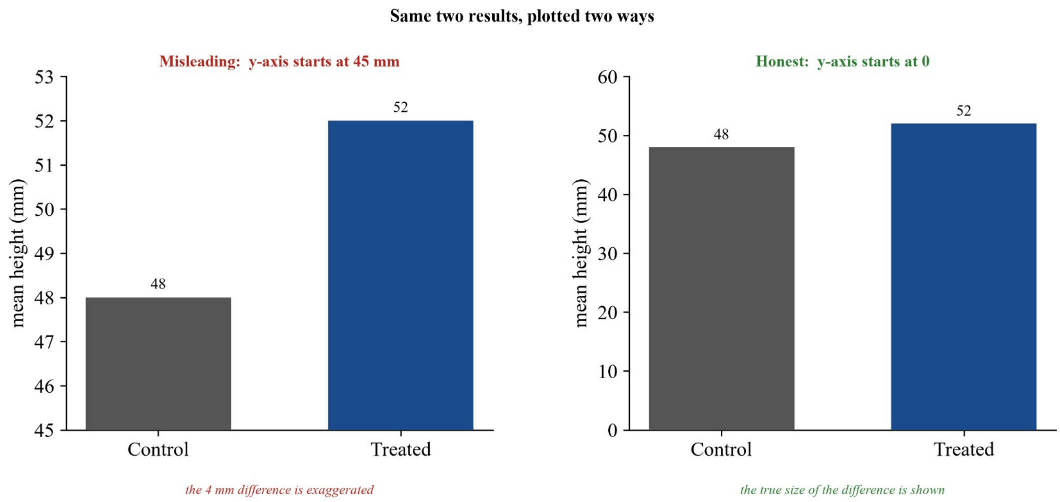
Scientific representations and conventions. Data and quantities are shown to shared conventions so that any reader reads them the same way:

- **units and symbols** — every measurement is given with its **unit** (48 mm, not "48"), using standard units and symbols, and quantities are quoted to a **consistent number of decimal places**;
- **scientific names** of species are written in a standard way — the **genus with a capital letter and the species in lower case, and the whole name in italics**, for example the fruit fly *Drosophila melanogaster*;
- **tables** are given a **number and a caption** (placed *above* the table), and each column heading carries the **variable and its unit** (so units are not repeated in every cell); the independent variable is usually the left-hand column (as in 6B);
- **figures** (graphs and diagrams) are given a **number and a caption** (placed *below* the figure), with both axes labelled with units;
- **every table and figure is referred to by its number in the text** ("the mean heart rate rose with temperature, as shown in Figure 1") — a table or graph that is never mentioned leaves the reader guessing why it is there.

(*Which* type of graph to choose, and how to draw a line of best fit, were covered in 6B; here the concern is the labelling, numbering and captioning conventions that make any graph readable.)

Presenting data honestly. A report must present data **truthfully**, so that a reader draws the same conclusion the data really support. Two common ways of misleading — sometimes by accident — must be avoided.

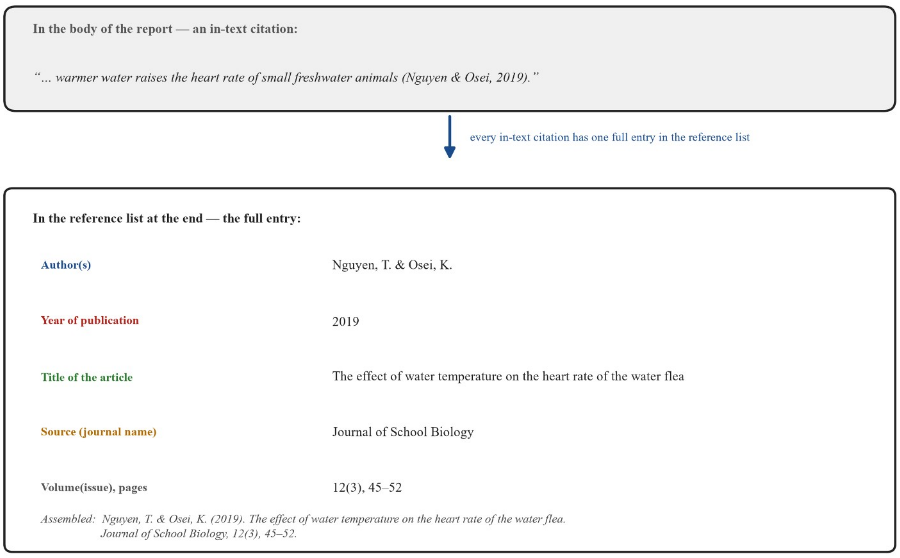
First, **the scale of a graph must not distort the data.** If the vertical axis does not start at zero, a small real difference can be made to look huge. The two graphs below plot **exactly the same two results**: on the left the axis starts at 45 mm, so a 4 mm difference looks enormous; on the right the axis starts at zero, showing the difference as it really is.



Second, **all the relevant data must be shown**, including results that do not fit the expected pattern. Quietly leaving out an inconvenient reading, or an anomaly, to make a trend look neater is **dishonest** — it hides evidence from the reader. An anomaly should be **shown and discussed** (and only set aside, with the reason stated, if it can be traced to a known fault — see the treatment of outliers in 6B). Honest presentation is part of scientific **integrity**: recording and reporting *all* the data, not just the results you hoped for.

Referencing and acknowledging the work of others. Almost every investigation builds on ideas, facts or methods first published by other people. Whenever you use someone else's work, you must **acknowledge it** by **referencing** the source. Referencing does several jobs at once: it **gives credit** to the people who did the original work, it lets a reader **find and check the source** for themselves, it shows the **evidence** your ideas rest on, and it keeps you clear of **plagiarism** — presenting someone else's words or ideas as your own, which is a serious breach of scientific integrity.

Referencing has two linked parts. Wherever a borrowed idea appears in the text, you place a short **in-text citation** (usually the author's surname and the year). Every in-text citation then has one full matching entry in the **reference list** at the end, giving enough detail for the reader to locate the exact source.



To use a source properly, put the idea **in your own words** and add the citation (or, if you use the exact words, place them in quotation marks and cite them) — copying sentences without citing is plagiarism even if only a few words are changed. You should also **acknowledge people who helped** — someone who lent equipment, gave advice or assisted with the work — in an acknowledgements note.

When an investigation draws on **Aboriginal and Torres Strait Islander knowledge** — for example, knowledge of the properties or uses of an Australian species — that knowledge and the community or Traditional Owners it belongs to must be **acknowledged and attributed** in the same way as any other source. Such knowledge is not "common knowledge” that needs no citation: it should be used only with appropriate **permission**, following cultural protocols, and credited to its custodians, out of **respect** for the people who hold and care for it.

Communicating the key findings and implications to an audience. Good communication is also shaped by **who will read it and why**. The same finding is written differently for different audiences: for other scientists you use full technical terminology, detailed methods and complete data; for the general public you use plain language, keep jargon to a minimum, and focus on the **key finding** and what it means for people. What must never change is the honesty of the message. When you present findings, state the **conclusion** (what the data show, answering the aim) clearly, and separate it from any **implication** (the wider real-world meaning or use of the finding — see 6B), so that a reader is never misled into thinking a broad suggestion is a directly measured result.

Done well, a report or poster lets a reader anywhere follow exactly what you did, trust what you found, and take the work further. Done poorly — a jumbled structure, a misleading graph, an uncited source, a finding overstated as “proof” — it wastes good data and can mislead the very people it is meant to inform.

Worked examples

Example 1 — scaffolded

The following four statements each come from a student’s scientific report on how storage temperature affects the germination of radish seeds. State the section of the report in which each belongs, and give a reason.

(1) “It is hypothesised that a higher storage temperature will increase the percentage of radish seeds that germinate.” **(2)** “The percentage of seeds that germinated at each temperature is shown in Table 1.” **(3)** “Fifty radish seeds were placed on damp paper at 10, 20 and 30 °C and the number germinating after five days was counted.” **(4)** “The data supported the hypothesis, although only one variety of radish was used, which limits how far the conclusion can be generalised.”

Working	Comment
(1) states the **hypothesis** — a proposed answer written before the data — so it belongs in the **introduction**.	The aim and hypothesis are set out in the introduction.
(2) presents a result (points the reader to the data table) without interpreting it, so it belongs in the **results**.	The results section reports the data; it does not yet say what they mean.
(3) describes what was actually done, step by step, so it belongs in the **methodology and method**.	The method must be detailed enough for someone else to repeat it.
(4) interprets the data against the hypothesis and names a limitation, so it belongs in the **discussion**.	Relating results to the hypothesis, and noting limitations, is the job of the discussion.

Example 2 — scaffolded

A student wrote this sentence in a report: *“I think the amazing fruit flies (drosophila melanogaster) totally proved that warmth makes them grow way faster, gaining 0.4 each day.”* Rewrite the sentence so that it follows the conventions of scientific writing, and explain each change.

Working	Comment
Remove the personal, emotive words (“I think”, “amazing”, “totally”, “way”) and write it impersonally in the past tense.	Scientific writing is objective and impersonal, not a personal opinion.
Change “proved” to “**supported the hypothesis**”.	Data can support or not support a hypothesis, but never *prove* it.
Write the species name correctly: *Drosophila melanogaster* — **genus capitalised, species lower case, whole name in italics**.	Scientific names follow a fixed convention.
Add the missing **unit** to the measurement — “a mean mass gain of 0.4 **mg** per day”.	Every measurement must be reported with its unit.

Working	Comment
Rewritten: **“The results supported the hypothesis that a higher temperature increases the growth rate of the fruit fly *Drosophila melanogaster*, with a mean mass gain of 0.4 mg per day.”**	The meaning is kept, but the wording now meets scientific conventions.

Example 3 — unscaffolded

For an introduction, a student copied two sentences word-for-word from a website about enzymes and pasted them into her report without saying where they came from. Explain what is wrong with this, give two reasons why scientists reference their sources, and state what an in-text citation and its matching reference-list entry should contain.

Copying sentences from a website and presenting them as her own writing, without acknowledging the source, is **plagiarism** — using someone else’s words or ideas as if they were her own — which is a serious breach of scientific **integrity**. Scientists **reference** the sources they use for several reasons: firstly, to **give proper credit** to the people who did the original work; and secondly, to let a reader **find and check the source** for themselves, so the claim can be verified rather than simply believed. (Referencing also shows the evidence an argument rests on.) To reference the material properly the student should put the idea **in her own words** and add an **in-text citation** — the **author’s surname and the year of publication** — at that point in the text; every such citation must then have one full entry in the **reference list**, giving the **author(s), year, title of the work, and the source** (such as the website or journal, with the details needed to locate it). ∴ she must rewrite the idea in her own words and cite the source both in the text and in the reference list, so the work is credited and can be checked.

Example 4 — unscaffolded

While writing up an investigation, a student notices that one of her ten readings does not fit the trend of the others. To make her graph look neater, she decides to leave that reading out of the graph altogether and not mention it. Explain why this is a problem for the honesty of her report, and describe what she should do instead.

Quietly removing a reading that does not fit, and not mentioning it, means the report **no longer shows all of the data that were actually collected** — it hides evidence from the reader so that the trend looks stronger and neater than the real data support. This breaches scientific **integrity**, which requires that **all** the data be recorded and reported honestly, not just the results that suit the expected pattern; a reader relying on the tidied graph could be misled. Instead, she should **include the anomalous reading** in her results (it was genuinely measured) and **discuss it** in the discussion section. If she can trace the odd reading to a known fault or mistake, she may set it aside from a calculated mean — but only with the **reason stated openly** so the reader can see exactly what was done and why. ∴ honest reporting means showing every reading and openly discussing any anomaly, rather than silently deleting data to improve the appearance of the results.

Practice questions

Scaffolded

Q1. Define each of the following terms: (a) plagiarism; (b) reference list; (c) in-text citation.

Q2. A scientific report is set out in sections, each with its own job. (a) Name the section in which the aim and hypothesis are stated. (b) Name the section in which the data are presented, without being interpreted. (c) Name the section in which the results are interpreted and related to the hypothesis.

Q3. Scientific writing follows language conventions. (a) Explain why a report should say the data “support” a hypothesis rather than “prove” it. (b) State how the scientific name of a species should be written. (c) State why an abbreviation is written out in full the first time it is used.

Q4. Data must be presented to shared conventions. (a) State what a column heading in a results table should contain. (b) Explain why every table and graph in a report should be referred to in the text. (c) State why each measurement is reported with its unit and to a consistent number of decimal places.

Q5. A report must present its data honestly. (a) Explain why all the data collected should be shown, including any anomalous readings. (b) State one way in which the axis of a graph can be drawn so that it misleads the reader. (c) Explain why the results section is kept separate from the discussion section.

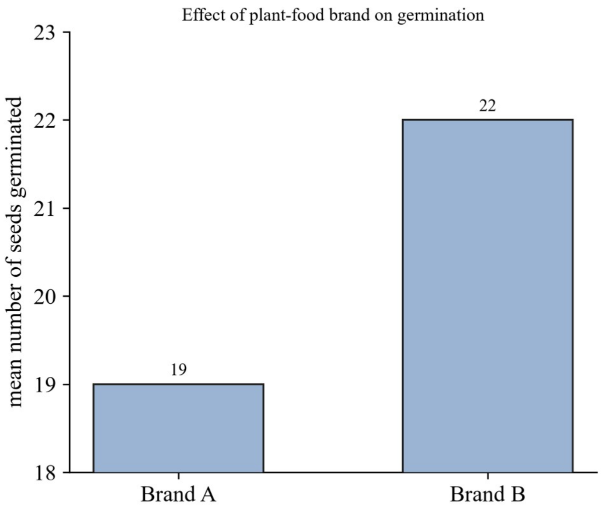
Q6. Scientists reference and acknowledge the work of others. (a) State two reasons scientists reference the sources they use. (b) State why copying a sentence from a source and changing only a few of its words, without citing it, is still plagiarism. (c) State why a report acknowledges a person who provided assistance with the investigation.

Unscaffolded

Q7. Distinguish between the results section and the discussion section of a scientific report. *(2 marks)*

Q8. In her investigation a student followed a method she found in a published journal article, and was shown how to set up the data logger by a laboratory technician. Describe how she should acknowledge each of these two contributions in her report. *(2 marks)*

Q9. *(Stimulus.)* A student drew the graph below to compare two brands of plant food, using the mean number of seeds (out of 25) that germinated with each brand.



(a) Explain why this graph could mislead a reader about the difference between the two brands.
(b) State how the graph should be redrawn so that it presents the data fairly.
(c) Name the principle of scientific communication that the graph fails to follow. *(4 marks)*

Q10. Explain why the methodology and method section of a report must be written in enough detail for another scientist to repeat the investigation, and state why it is written impersonally and in the past tense. *(3 marks)*

Q11. *(Stimulus.)* In the introduction of her report a student wrote: "Warmer water speeds up the heartbeat of small water animals." She had read this idea in an online article but did not cite it. Her reference list contained the entry:

Okoro, L. The heart rate of freshwater invertebrates. *Journal of School Biology*, 8(2), 33–40.

(a) The reference-list entry is missing an important element. Identify it, and explain why it matters.
(b) Identify one other referencing problem in what the student did, and state how to fix it. *(3 marks)*

Q12. *(Data presentation.)* A student counted the number of oxygen bubbles released by pondweed in one minute at each of three temperatures, and presented her results as the table below.

Temperature	Rate
10 degrees	5 bubbles
20 degrees	11.0 bubbles
30 degrees	18 bubbles

(a) Identify two conventions of presenting data in a table that this table breaks.
(b) Rewrite the two column headings so that the table follows the conventions.

(c) State one further convention that a well-presented table should follow. *(4 marks)*

Q13. A scientific investigation may be communicated as a written report or as a scientific poster. Explain how a poster communicates an investigation differently from a written report, and state two features of an effective poster. *(3 marks)*

Q14. A scientist must present the findings of the same investigation to (i) an audience of other scientists and (ii) a general public audience with no scientific training. Explain how the communication should differ between the two audiences, and why. *(3 marks)*

Q15. An investigation concluded that increasing the amount of a dissolved fertiliser increased the growth of a crop, up to an optimum concentration. (a) State one implication of this finding for a farmer. (b) Explain how an implication differs from the conclusion in what it communicates. (c) Explain why an implication should be clearly separated from the conclusion when the findings are communicated. *(3 marks)*

Q16. A research team studies an Australian native plant that Aboriginal peoples have long used, and they draw on that traditional knowledge in planning their investigation. Explain how the team should acknowledge this knowledge in their report, and why acknowledging it in this way matters. *(3 marks)*

Q17. A student investigated the effect of daily light exposure on the height of bean seedlings, and found that the seedlings given more light were taller after three weeks. She titled her report "Experiment 4", and wrote as her conclusion: "This was a really good experiment and the plants did what I expected." Identify what is wrong with the title and with the conclusion, and write an improved version of each. *(3 marks)*

Q18. *(Synthesis.)* A student investigated whether adding powdered eggshell (a source of calcium) to soil affects the growth of pea plants, measured as the mean number of new leaves grown in four weeks. Four pots were used at each eggshell amount, with all other conditions kept the same. Her mean results are shown below.

Eggshell added (g)	Mean number of new leaves
0	6
5	9
10	12
20	8

She now has to communicate her investigation as a scientific report. (a) List, in order, the main sections a scientific report should contain. (b) State the section in which her results table belongs, and the section that relates the results back to the hypothesis and notes any limitations and implications. (c) In her introduction the student included a fact about calcium and plant growth that she read in a plant science textbook. Explain what she must do to use this information properly, and state one reason referencing matters. (d) When graphing her means, the student started the vertical axis at 5 leaves rather than 0, which made the differences between the pots look much larger. Explain why this is misleading, and state how she should present the graph honestly. *(8 marks)*

Answers

Q1. (a) Presenting someone else's words or ideas as your own, without acknowledging the source. (b) A list at the end of a report giving a full entry for every source used. (c) A short note in the text (usually author surname and year) marking where a borrowed idea is used. **Q2.** (a) Introduction. (b) Results. (c) Discussion. **Q3.** (a) A later investigation could always give a different result, so data can support but never prove a hypothesis. (b) Genus capitalised, species lower case, whole name in italics (e.g. *Drosophila melanogaster*). (c) So the reader knows what it stands for and is not left guessing. **Q4.** (a) The variable and its unit. (b) So the reader knows why it is there and can connect the text to the data. (c) So results can be compared fairly and read consistently / unambiguously. **Q5.** (a) So no evidence is hidden and the report honestly reflects what was measured. (b) e.g. starting the vertical axis at a value other than zero (a truncated axis), which exaggerates a small difference. (c) So a reader can tell what was observed (results) from what it is claimed to mean (discussion). **Q6.** (a) Any two of: to give credit to the original workers; to let readers find/check the source; to show the evidence behind an idea; to avoid plagiarism. (b) The idea, and most of the wording, are still the source's, so presenting them uncited is still passing off someone else's work as your own. (c) To give them credit for their help (and to be honest about who contributed to the work). **Q7.** Results present the data (tables/graphs) without interpretation; the discussion interprets them, relates them to the hypothesis, and notes limitations and implications. **Q8.** Reference the journal article — an in-text citation where the method is described, plus a full entry in the reference list; name the technician's help in an acknowledgements note (assistance is acknowledged, not referenced). **Q9.** (a) Its vertical axis does not start at zero (truncated), so the small real difference is exaggerated and B looks far better than it really is. (b) Redraw with the axis starting at zero and a full, even scale. (c) Presenting data honestly / integrity. **Q10.** So another scientist can repeat it exactly (to check/reproduce the results); written impersonally and in past tense to record objectively what was actually done. **Q11.** (a) The year of publication is missing; the year lets a reader find the exact source and judge how recent it is. (b) The borrowed statement has no in-text citation; she must cite the source in the text — the author's surname and the year, i.e. "(Okoro, [year of publication])" once she has found the missing year — so it is credited and can be checked (otherwise it is plagiarism). **Q12.** (a) Any two of: units belong in the column heading, not repeated in every cell; the unit should be °C, not "degrees"; the values are given to inconsistent decimal places (5, 11.0, 18). (b) e.g. "Temperature (°C)" and "Rate (bubbles per minute)", with numbers only in the cells. (c) e.g. number the table and give it a caption (above the table) and refer to it in the text. **Q13.** A poster is condensed and visual — short text under headings with graphs/images doing most of the work, made to be read quickly — whereas a report is a longer continuous document. Two features: a clear title; a logical, uncluttered layout; readable text; visuals that carry the key points (any two). **Q14.** For scientists: full technical terms, detailed methods and complete data. For the public: plain language, minimal jargon, focus on the key finding and its meaning. Because effective communication must suit the audience's background and purpose. **Q15.** (a) e.g. the farmer should add fertiliser up to about the optimum concentration, as adding more wastes money and does not increase growth. (b) The conclusion states what the data show; the implication is the wider real-world meaning/application of that finding. (c) So the audience does not mistake a broader suggestion for a directly measured result. **Q16.** Acknowledge and attribute the knowledge to the specific Aboriginal community/custodians and cite it as a source, using it only with permission and following cultural protocols; it matters because it gives proper credit, respects the knowledge-holders' rights, and shows integrity. **Q17.** Title: "Experiment 4" does not say what was investigated — a title should name the variables, e.g. "The effect of daily light exposure on the height of bean seedlings". Conclusion: it gives a personal opinion about the experiment instead of answering the aim from the data — e.g. "Bean seedlings given more daily light grew taller over three weeks, supporting the hypothesis." **Q18.** (a) Title; introduction (aim and hypothesis); methodology and method; results; discussion; conclusion; references. (b) Results; discussion. (c) Put it in her own words and cite the source in-text and in the reference list; referencing gives credit / lets readers check it / avoids plagiarism (any one). (d) Starting the axis at 5 rather than 0 truncates it and exaggerates the differences between pots, misleading the reader; she should start the axis at 0 with a full, even scale.

Fully-worked solutions

Q1. (a) **Plagiarism** is **presenting someone else's words or ideas as if they were your own**, without acknowledging where they came from. (b) A **reference list** is the **list at the end of a report that gives a full entry for every source used**, with enough detail for a reader to locate each one. (c) An **in-text citation** is a **short note placed in the body of the report** (usually the author's surname and the year) that **marks where a borrowed idea has been used** and points to its full entry in the reference list.

Q2. (a) The **introduction**. (b) The **results**. (c) The **discussion**.

Q3. (a) Because a **later investigation could always produce a different result**, scientific evidence can **support** (or fail to support) a hypothesis but can never **prove** it beyond all doubt; "support" is the honest, tentative wording. (b) The scientific name is written with the **genus capitalised and the species name in lower case, with the whole name in italics** (for example *Drosophila melanogaster*). (c) An abbreviation is **written out in full at its first use** so that the **reader knows exactly what it stands for** and is not left to guess its meaning later in the report.

Q4. (a) A column heading should contain the **name of the variable and its unit** (so the unit does not have to be repeated beside every value in the column). (b) Every table and graph should be **referred to by number in the text** so the reader **knows why it is included and can connect the written argument to the data** it rests on; a figure never mentioned leaves its purpose unclear. (c) Reporting each value **with its unit and to a consistent number of decimal places** means the data can be **read unambiguously and compared fairly**, without the reader having to guess the unit or the precision.

Q5. (a) **All** the data should be shown so that **no evidence is hidden** and the report **honestly reflects what was actually measured**; leaving readings out to tidy a trend misrepresents the result. (b) Any one valid way, for example **starting the vertical axis at a value other than zero (a truncated axis)**, which makes a small difference between values look much larger than it is. (c) The **results** report **what was observed** and the **discussion** argues **what it means**; keeping them separate lets a reader **tell an observation apart from an interpretation**, rather than accepting a claim as if it were data.

Q6. (a) Any **two** of: to **give credit** to the people who did the original work; to let a reader **find and check** the source; to **show the evidence** an idea is based on; to **avoid plagiarism**. (b) Changing a few words leaves the **idea — and most of the wording — still the original author's**, so presenting it without a citation is still **passing off someone else's work as your own**; to use the source properly the idea must be put **genuinely into your own words and cited** (or the exact words placed in **quotation marks** and cited). (c) A person who assisted is acknowledged to **give them proper credit for their contribution** and to be **honest about who helped** produce the work.

Q7. The **results** section **presents the data** — the tables and graphs — **as they were obtained, without interpreting them**. The **discussion** section **interprets those data**: it says what they mean, **relates them to the hypothesis** (supported or not), and considers the **limitations and implications** of the investigation. *(1 mark: results present the data without interpretation; 1 mark: discussion interprets the data / relates them to the hypothesis.)*

Q8. The published method is a **source of information**, so it must be **referenced**: an **in-text citation** (author's surname and year) where the method is described, pointing to a **full entry in the reference list** so a reader can locate the article. The technician's help is a **source of assistance**, which is not referenced but **named in an acknowledgements note** — stating who helped and what they did — so the technician is credited and the reader can see who contributed to the work. *(1 mark: cite the article in-text and list it in the reference list; 1 mark: acknowledge the technician's assistance in an acknowledgements note.)*

Q9. (a) The graph's **vertical axis does not start at zero — it is truncated** (it begins at 18), so the **small real difference between the brands is exaggerated**: Brand B's bar looks several times taller than Brand A's, when the means (22 and 19 out of 25) are in fact close. This could mislead a reader into thinking Brand B is far better than it is. (b) The graph should be **redrawn with the vertical axis starting at zero** and a **full, even scale**, so the bars show the **true size of the difference**. (c) It fails to **present the data honestly** (scientific **integrity**). *(a: 2 marks — identifies the truncated/non-zero axis, and explains it exaggerates the difference/misleads; b: 1 mark — redraw with the axis from zero / full scale; c: 1 mark — honesty/integrity in presenting data.)*

Q10. The **method must be described in enough detail that another scientist could carry out the same investigation exactly** — the same steps, quantities and conditions. This matters because it lets others **repeat the investigation to check whether they obtain the same results** (reproducibility) and lets a reader **judge whether the method was sound**. It is written **impersonally and in the past tense** because a report is an **objective record of what was actually done**, not a personal account, so the focus stays on the procedure rather than on the writer. *(1 mark: detailed enough to repeat exactly; 1 mark: so the results can be checked/reproduced or the method evaluated; 1 mark: impersonal, past tense = an objective record of what was done.)*

Q11. (a) The entry is **missing the year of publication**. The **year** matters because it lets a reader **find the exact source** among an author's works and **judge how recent (and therefore how current) the information is**. (b) The other problem is that the borrowed statement in the introduction **has no in-text citation** — the idea was taken from Okoro's article but is not credited where it is used. To fix it, she should **add an in-text citation** at that point, giving the **author's surname and the year of publication** — *(Okoro, [year])*, using the year she recovers from the article to repair the reference-list entry in part (a) — so the source is credited and the claim can be checked; without it the sentence is **plagiarised**. *(a: 1 mark — missing the year; 1 mark — why the year matters (locate the source / judge how recent); b: 1 mark — the uncited claim needs an in-text citation, with the fix.)*

Q12. (a) Any **two** of: the **units are repeated in every cell** instead of being placed once in the **column heading**; the temperature unit is written as "**degrees**" rather than the correct symbol **°C**; the rate values are given to **inconsistent decimal places** (5, 11.0 and 18). (b) The headings should read, for example, **"Temperature (°C)"** and **"Rate (bubbles per minute)"**, with the cells holding **numbers only** (10, 20, 30 and 5, 11, 18). (c) One further convention, for example: the table should be **given a number and a caption placed above it**, and it should be **referred to by number in the text**. *(a: 1 mark each for two valid convention errors = 2; b: 1 mark — both headings rewritten with the unit in the heading; c: 1 mark — one further valid table convention. Total = 4.)*

Q13. A **poster** communicates the investigation in a **condensed, highly visual** form: the same sections appear, but as **short blocks of text under clear headings with graphs, diagrams and images carrying most of the message**, designed to be **read quickly** (often at a glance while standing in front of it) — unlike a **written report**, which is a **longer, continuous written document** read in full. Two features of an effective poster (any **two**): a **clear, informative title**; a **logical, uncluttered layout** that guides the eye; **readable text** that is not overcrowded; **visuals that carry the key points** clearly. *(1 mark: poster is condensed/visual and read quickly vs report is a longer written document; 1 mark + 1 mark: two valid features of an effective poster.)*

Q14. For the **audience of scientists**, the findings can be presented with **full technical terminology, the detailed method, and the complete data**, because that audience has the background to follow them. For the **general public**, the same findings should be given in **plain language with the jargon kept to a minimum**, focusing on the **key finding and what it means for people** rather than the technical detail. The communication differs because **effective communication must suit the audience's prior knowledge and the purpose** — the message a reader can actually understand and use depends on who they are. *(1 mark: scientist version = technical terms / full method and data; 1 mark: public version = plain language, minimal jargon, key finding and meaning; 1 mark: because communication must suit the audience's background/purpose.)*

Q15. (a) A reasonable implication: the farmer should **add the fertiliser up to about the optimum concentration**, because **adding more than that wastes money and does not increase growth** (and may harm the crop). (b) The **conclusion** states **what the data show** — the relationship found, answering the aim — whereas the **implication** is the **wider real-world meaning or application** of that finding, beyond the experiment itself. (c) The implication must be **kept separate from the conclusion** so that the audience does **not mistake a broader, applied suggestion for a result the data directly measured** — keeping the honest distinction between evidence and its wider interpretation. *(1 mark: a valid implication for the farmer; 1 mark: conclusion = what the data show vs implication = wider real-world meaning; 1 mark: separating them prevents a suggestion being taken as a directly measured result.)*

Q16. The team should **acknowledge and attribute the traditional knowledge to the specific Aboriginal community or custodians it belongs to**, citing it as a source in the report just as they would any other source, and they should have **used it only with the community's permission and in line with cultural protocols**. This matters because it **gives proper credit to the knowledge-holders**, **respects their ownership of and rights over that knowledge**, and shows **scientific integrity** (as well as letting a reader see where the idea came from). *(1 mark: acknowledge/attribute and cite the knowledge to the community/custodians; 1 mark: use only with permission / following cultural protocols; 1 mark: why — it gives credit, respects their rights, shows integrity.)*

Q17. The **title** "Experiment 4" **does not say what was investigated** — a title must name the variables so a reader knows at a glance what the report is about; an acceptable improved title is **"The effect of daily light exposure on the height of bean seedlings"**. The **conclusion** is also faulty: it gives a **personal opinion about how the experiment went** rather than a short statement that **answers the aim and is supported by the data**, and it does not report the relationship that was found. An acceptable rewritten conclusion is **"Bean seedlings given more daily light grew taller over three weeks, supporting the hypothesis."** *(1 mark: the title does not name what was investigated / the variables, with an acceptable improved title; 1 mark: the conclusion states a personal opinion instead of answering the aim from the data; 1 mark: an acceptable rewritten conclusion stating the finding.)*

Q18. (a) In order: **title; introduction (containing the aim and hypothesis); methodology and method; results; discussion; conclusion; references**. (b) The results **table** belongs in the **results** section; the section that **relates the results back to the hypothesis and notes limitations and implications** is the **discussion**. (c) To use the textbook fact properly she must **put it in her own words and cite the source** — an in-text citation where she uses it, plus a full entry in the reference list; referencing matters because it **gives credit to the original author / lets a reader check the source / avoids plagiarism** (any one). (d) Starting the vertical axis at **5 rather than 0 truncates the axis**, which **exaggerates the differences between the pots** and could **mislead a reader** into thinking the effect of the eggshell is larger than it is; to present the data honestly she should **start the vertical axis at 0** and use a **full, even scale** so the true size of the differences is shown. *(a: 2 marks — the sections in the correct order; b: 1 mark — results holds the table; 1 mark — discussion relates to the hypothesis and notes limitations/implications; c: 1 mark — paraphrase and cite in-text and in the reference list; 1 mark — one valid reason referencing matters; d: 1 mark — truncated axis exaggerates the differences / misleads; 1 mark — start the axis at zero with a full scale. Total = 8.)*

Topic 3 Test A — Scientific investigation and primary data

Reading time: 5 minutes. Writing time: 25 minutes. 20 questions, 20 marks. No calculator, no notes. This test covers Chapter 6 (the cross-study specification: designing an investigation, scientific evidence, and communicating science). Every question can be answered from Chapter 6 alone — no recall of cell, body-system, genetics or ecology content is required. Choose the response that is correct or that best answers the question. A correct answer scores 1 mark; an incorrect answer scores 0. Marks are not deducted for incorrect answers. Diagrams are not drawn to scale.

Question 1

A student is planning an investigation into how the number of hours of light a day affects the number of flowers produced by a chrysanthemum plant. Which one of the following statements is a **hypothesis**?

A. It is hypothesised that increasing the number of hours of light a day will decrease the number of flowers produced by a chrysanthemum plant.

B. To determine whether the number of hours of light a day affects the number of flowers produced by a chrysanthemum plant.

C. Does the number of hours of light a day affect the number of flowers produced by a chrysanthemum plant?

D. If chrysanthemums are given 8, 12 and 16 hours of light a day, then the plants given 16 hours will produce the fewest flowers.

Question 2

Identical flasks of a yeast suspension were each given a different mass of sugar — 1 g, 2 g, 4 g or 8 g — kept at 30 °C, and the volume of carbon dioxide each produced in 20 minutes was measured. The same volume of yeast suspension was placed in every flask. The independent variable in this investigation is

A. the volume of carbon dioxide produced in 20 minutes.

B. the mass of sugar added to the flask.

C. the temperature at which the flasks were kept.

D. 1 g, 2 g, 4 g and 8 g.

Question 3

A student is testing whether a commercial plant tonic increases the number of new leaves grown by pot plants. Each treated plant is watered with the tonic powder dissolved in tap water. The most appropriate control is a plant watered with

A. nothing at all.

B. tap water containing none of the tonic powder.

C. twice the mass of tonic powder dissolved in tap water.

D. distilled water containing none of the tonic powder.

Question 4

To check an electronic balance, a student weighed a certified 100.0 g reference mass five times. The five readings were 101.1, 101.3, 101.2, 101.2 and 101.2 g, giving a mean of 101.2 g. This set of readings is

A. accurate but not precise.

B. both accurate and precise.

C. neither accurate nor precise.

D. precise but not accurate.

Question 5

A thermometer used throughout an experiment was later found to read 1.0 °C higher than the true temperature for every reading taken. This is

A. a random error, and taking more readings and calculating a mean would reduce it.

B. a systematic error, and taking more readings and calculating a mean would remove it.

C. a systematic error, and taking more readings and calculating a mean would not reduce it.

D. a random error, and it would be removed by the student taking more care.

Question 6

A student repeats her measurement of the same quantity a week later, this time using a different balance and with a different classmate reading the scale. Testing the measurement in this way checks its

A. accuracy, because the true value is now known.

B. repeatability, because the same quantity is being measured again.

C. validity, because a different person is now involved.

D. reproducibility, because the measurement has been repeated under changed conditions — a different person and different equipment.

Question 7

A researcher wants to find out whether trees growing closer to a busy road carry fewer lichens on their bark. The distance of a tree from the road cannot be changed by the researcher. The most suitable methodology is

A. a correlational study.

B. a controlled experiment.

C. modelling.

D. a simulation.

Question 8

The mass of a picked apple kept in a cool room was measured after 2, 4, 6 and 8 weeks. Using the graph of these results to estimate the mass after 5 weeks, and using it to estimate the mass after 20 weeks, are respectively

A. interpolation and interpolation.

B. interpolation and extrapolation.

C. extrapolation and interpolation.

D. extrapolation and extrapolation.

Question 9

A student plans to use a chemical stain in an investigation. Before any work begins she must write a risk assessment. This risk assessment must be informed by

A. the results of a trial run, which show how the stain behaves.

B. the manufacturer's advertising material, which describes what the stain is used for.

C. the stain's safety data sheet, which sets out its hazards and how it must be handled, stored and disposed of.

D. her logbook, in which each step of the method is dated and recorded.

Question 10

During fieldwork a student writes in her logbook that a frog's skin was "smooth and olive-green", and afterwards downloads the maximum daily air temperatures for the study week from a national weather bureau's website. These two records are, respectively,

A. qualitative and primary; quantitative and secondary.

B. quantitative and primary; qualitative and secondary.

C. qualitative and secondary; quantitative and primary.

D. quantitative and secondary; qualitative and primary.

Question 11

A student compares the mean number of earthworms found in soil samples of the same size taken from four different sites — a pasture, a forest, an orchard and a roadside verge. The most appropriate way to display these results is

A. a line graph, with the four sites joined by a line.

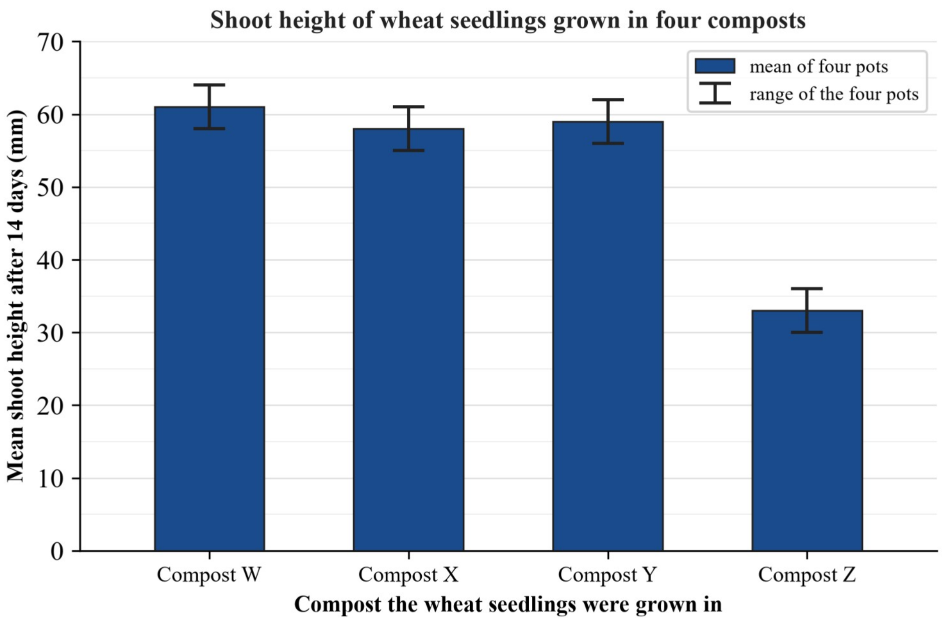
B. a line graph, with the four sites on the vertical axis.

C. a column graph, with the columns drawn touching one another.

D. a column graph, with a gap between the columns.

Use the following information to answer Questions 12 and 13.

Wheat seedlings were grown in four different composts, labelled W, X, Y and Z. Four pots of each compost were prepared and kept under the same light, temperature and watering, and the mean shoot height of the seedlings in each pot was measured after 14 days. The results are shown below; the bars show the range of the four pots.



Question 12

Which one of the following differences is supported by these data?

A. Between compost W and compost Y.

B. Between compost X and compost Y.

C. Between compost Z and each of the other three composts.

D. None — these data support no difference between any of the four composts.

Question 13

The range bars for compost W and compost Y overlap. It follows that

A. compost W and compost Y produce the same shoot height.

B. compost W must produce taller seedlings, because its mean is the higher of the two.

C. the difference between these two means was produced by a systematic error.

D. the difference between these two means could have been produced by the spread of the data alone, so these data do not support a difference between compost W and compost Y.

Use the following information to answer Questions 14 and 15.

A student counted the number of aphids on each of five bean plants growing in one plot. The counts were 22, 25, 24, 6 and 23 aphids. Her logbook records nothing unusual about any of the five plants.

Question 14

Which one of the counts is an outlier?

A. 25

B. 24

C. 22

D. 6

Question 15

Because the logbook records nothing unusual about any of the plants, the mean number of aphids per plant that should be reported is

A. 6.

B. 20.0.

C. 23.5.

D. 25.

Question 16

In a survey of 30 home gardens, gardens that had a thicker layer of mulch tended to have fewer weeds. Nothing in any garden was changed by the researcher. Which statement is best supported by these data?

A. In these 30 gardens, those with more mulch tended to have fewer weeds; the data show an association only.

B. Thicker mulch causes a garden to have fewer weeds.

C. Having fewer weeds causes gardeners to add thicker mulch.

D. The association must have arisen by chance, because nothing was changed.

Question 17

A student writes: “Cell theory is only a theory, so once there is enough evidence it will become a law.” The student’s statement is wrong because

A. a theory is only a guess, so it could never be supported by enough evidence.

B. a law is an explanation and a theory is only a description of a pattern.

C. a law describes a consistent pattern observed in nature and a theory explains it — a theory does not turn into a law.

D. cell theory has already been proved, so it is a law now.

Question 18

A model predicts that the rate at which a plant takes up water rises as the air temperature rises. A student’s data show water uptake rising as temperature rises, matching the model’s prediction. These data

A. prove that the model is correct.

B. are consistent with the model and support it.

C. challenge the model.

D. cannot be compared with a model.

Question 19

Which one of the following sentences follows the conventions of scientific communication?

A. Individuals of *Austrofluvia media* were kept at 18 °C in 500 mL of aged tap water.

B. Individuals of *austrofluvia Media* were kept at 18 °C in 500 mL of aged tap water.

C. Individuals of Austrofluvia media were kept at 18c in 500 mL of aged tap water.

D. Individuals of *Austrofluvia media* were kept at 18°C in 500 mLs of aged tap water.

Question 20

A student reads a fact on a science website, rewrites it in her own words, and includes it in the introduction of her report without giving any citation. This is

A. acceptable, because she has put the fact into her own words.

B. acceptable, because a single fact is common knowledge.

C. plagiarism, because the idea came from another source and has not been credited.

D. fabrication of data, because the fact was not produced by her own investigation.

End of Topic 3 Test A

Test A — solutions

Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	A	6	D	11	D	16	A
2	B	7	A	12	C	17	C
3	B	8	B	13	D	18	B
4	D	9	C	14	D	19	A
5	C	10	A	15	B	20	C

Q1. A — a hypothesis is a testable statement that commits to a direction. B is the aim (states the purpose, predicts nothing), C is the research question, and D is a prediction (the specific “if … then …” result expected).

Q2. B — the independent variable is the quantity deliberately changed, the mass of sugar, not the list of values chosen for it: D gives its levels, A gives the dependent variable, and C is a controlled variable.

Q3. B — the control must differ from the treated plants in exactly one thing, the tonic; tap water without the powder supplies that. A and D each differ in a second way as well (no water at all; a different kind of water), and C is simply a higher level of the independent variable.

Q4. D — the readings lie within 0.2 g of one another, so they agree closely and are precise; but their mean, 101.2 g, is 1.2 g above the certified 100.0 g, so on average they are not accurate. This one-directional offset is the signature of a systematic error.

Q5. C — a fault that pushes every reading the same way by the same amount is a systematic error, and an average can wash out only variation that falls on either side of the true value, so repeating and averaging changes nothing. It must be fixed at its source (recalibrate the thermometer).

Q6. D — the same quantity is measured again but under deliberately changed conditions (a different person and different equipment), which tests reproducibility; repeatability (B) would keep the same person, method and equipment.

Q7. A — because the factor of interest, the distance from the road, cannot be manipulated, a controlled experiment (B) is impossible; the researcher observes the natural association between distance and lichen cover, which is a correlational study.

Q8. B — 5 weeks lies between two measured times, so estimating there is interpolation; 20 weeks lies outside the range investigated (2–8 weeks), so estimating there is extrapolation, which the data give no evidence for.

Q9. C — a risk assessment must be written before any work begins and, for every chemical used, must be informed by that chemical’s safety data sheet (SDS), which sets out its hazards and how it must be handled, stored, used and disposed of. A trial run (A) exposes the student to the hazard before it has been assessed, advertising material (B) is not a safety document, and the logbook (D) records what was done, not what the substance can do.

Q10. A — the note describes a quality in words, so it is qualitative, and the student generated it herself, so it is primary; the temperatures are measured numbers produced by somebody else and collated for use here, so they are quantitative and secondary.

Q11. D — the independent variable is categorical (four separate sites), so a column graph with gaps is required; the gaps show that nothing exists between the categories. Joining the categories with a line (A) claims values in between, and touching columns (C) is the convention for a continuous variable.

Q12. C — compost Z’s range (30–36 mm) reaches none of the other three, so a real difference between Z and each of W, X and Y is supported. Every pair among W (58–64), X (55–61) and Y (56–62) overlaps, so those differences are not supported, and D ignores Z altogether.

Q13. D — overlapping range bars mean the two composts produced pots covering some of the same values, so the gap between their means could have come from the spread alone and no difference is supported. Overlap does not show the composts are identical (A), the higher mean alone settles nothing (B), and overlap says nothing about the cause of any difference (C).

Q14. D — the count of 6 sits far below the tight band of the other four (22–25); a value this far outside the pattern of the rest is an outlier.

Q15. B — the logbook records no fault for any plant, so there is no reason to discard the low count, and dropping it would be falsifying the data. All five counts are kept: mean = (22 + 25 + 24 + 6 + 23) ÷ 5 = 100 ÷ 5 = 20.0. Answer C is the (improper) mean after discarding the 6.

Q16. A — the two variables were only observed, never manipulated, so the data establish an association within these gardens and nothing more. B and C each assert a cause that a correlational survey cannot establish, and D wrongly rules out every explanation except chance.

Q17. C — a law and a theory do different jobs: a law **describes** a consistent pattern observed in nature, while a theory **explains** it. They are different kinds of statement, so no amount of extra evidence turns one into the other. A theory is not a guess (A) — it is among the strongest explanations science has; B swaps the two round; and scientific claims are supported by evidence, never "proved" (D).

Q18. B — data that match a model's prediction are consistent with the model and support it. A single investigation never "proves" a model (A); the data do not fail the prediction, so they do not challenge it (C); and matching predictions is exactly how a model is tested against data (D).

Q19. A — the binomial is italicised with the genus capitalised and the species name entirely in lower case, there is a space between the number and the unit symbol, and the symbol is not pluralised. B reverses the capitalisation, C leaves the name unitalicised and writes "18c" (not a unit), and D closes up the space before °C and pluralises mL.

Q20. C — a citation credits the source of an idea; putting the idea into her own words does not remove the need to credit where it came from, so an uncited borrowed idea is plagiarism. B is wrong (a specific fact taken from a source is not common knowledge), and D confuses plagiarism with the fabrication of data.

Topic 3 Test B — Scientific investigation and primary data

Writing time: 50 minutes. Total 40 marks. No calculator, no notes. This test covers Chapter 6 (the cross-study specification: designing an investigation, scientific evidence, and communicating science). Every question can be answered from Chapter 6 alone — no recall of cell, body-system, genetics or ecology content is required. Answer all questions in the spaces provided. Where more than one mark is available, full marks require the depth that the command term and the mark allocation ask for. Diagrams are not drawn to scale.

Question 1 (8 marks)

A student wants to find out whether adding sugar to the water in a vase makes cut flowers last longer. She stands six roses in a vase of sugar water and six carnations in a vase of plain water, keeping both vases side by side on the same bench. After seven days she writes in her results: "the roses looked fresher".

a. State the aim of this investigation, and write a testable hypothesis for it. 2 marks

b. Explain why "looked fresher" is not an adequate dependent variable, and rewrite it as a dependent variable that could actually be measured, stating what would be counted or measured and over what period. 2 marks

c. Identify one confounding variable in this method, and explain why it prevents any conclusion being drawn about the sugar. 2 marks

d. State the change that must be made to the number of vases used. 1 mark

e. State one variable, other than the one you named in part **c**, that should be kept the same for both groups. 1 mark

Question 2 (7 marks)

A student investigated whether the concentration of dissolved salt in the watering solution affects the germination of cress seeds. At each salt concentration she set up three dishes, each sown with 40 seeds, and counted how many had germinated after four days. Her counts are shown in Table 1.

Table 1 Number of cress seeds (out of 40 sown per dish) that germinated after four days

Salt concentration (g/L)	Dish A	Dish B	Dish C
0	29	31	30
5	23	25	24
10	17	19	18
15	8	10	9

a. Calculate the mean number of seeds that germinated at each salt concentration. Show your working. 2 marks

b. Express the mean at 0 g/L as a percentage of the 40 seeds sown in a dish. 1 mark

c. Calculate the percentage change in the mean from 0 g/L to 10 g/L. Show your working. 1 mark

d. Write, in its simplest form, the ratio of the mean at 0 g/L to the mean at 10 g/L. 1 mark

e. Describe the trend shown by the means, using directional language and quoting values. 2 marks

Question 3 (6 marks)

To compare the leaves of a plant grown in the shade with those grown in the sun, a student counted the number of stomata (tiny pores) she could see in one field of view of a microscope on the underside of each leaf.

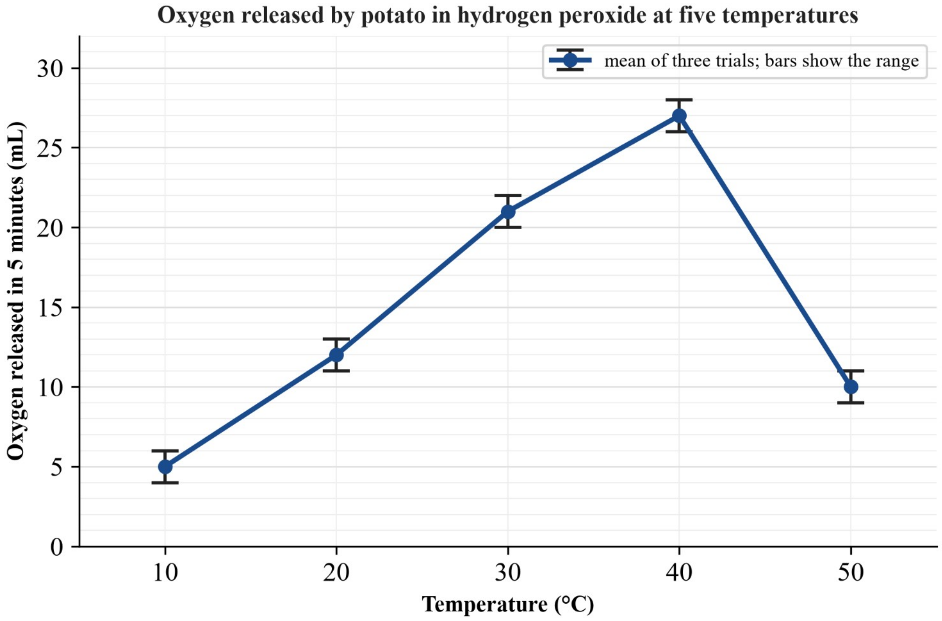
a. To check her technique she counted one and the same field of view five times, without moving the slide, and recorded 31, 28, 33, 29 and 30 stomata. The number of stomata in that one field of view cannot change. Name the type of error responsible for this variation, and state what she should do about it. 2 marks

b. She later realised she had used the higher-power (×40) objective for the sun leaves and the lower-power (×10) objective for the shade leaves, so the field of view covered a much smaller area of leaf for the sun leaves. Explain why this makes her comparison invalid. 2 marks

c. State whether counting several fields of view on each leaf, rather than one, improves the reliability or the validity of her stomata counts, and justify your answer. 2 marks

Question 4 (6 marks)

A student investigated how temperature affects the activity of the enzyme catalase, using pieces of potato of a fixed mass added to hydrogen peroxide. At each temperature she ran three trials and measured the volume of oxygen released in five minutes. Her mean results are shown in Figure 1.



a. Describe the trend shown by these data, using directional language and quoting values from the graph. 2 marks

b. The student's draft conclusion reads: "A higher temperature increases the activity of catalase." Rewrite this as an evidence-based conclusion. Your conclusion must refer to the data and must carry an appropriate degree of confidence. 2 marks

c. State one implication and one limitation of this investigation, and make clear which is which. 2 marks

Question 5 (7 marks)

A student plans to investigate whether a person's dominant hand has a stronger grip than their non-dominant hand. She will measure the grip strength of 25 volunteer classmates on each hand using a hand-grip meter, and will compare her results with grip-strength figures published by a sports institute.

a. Identify the independent variable and the dependent variable in this investigation. 2 marks

b. The student's own grip-meter readings and the published grip-strength figures are two different kinds of data. Name each kind, and justify your answer. 2 marks

c. Name one ethical concept the student should apply when working with the volunteers, and state one thing she must do to satisfy it. 2 marks

d. Before she begins, the student must write a risk assessment. State one risk to the volunteers that it must address. 1 mark

Question 6 (6 marks)

A student is writing up her investigation as a scientific report and a poster.

a. Name the section of a scientific report in which the aim and hypothesis are stated, and the section in which the results table is placed. 2 marks

b. When graphing her results, the student started the vertical axis at 20 rather than at 0, which made a small difference between two groups look large. Explain why this is misleading, and state how she should present the graph honestly. 2 marks

c. Her investigation drew on Aboriginal and Torres Strait Islander knowledge of how a native plant responds to fire. State how she must treat this knowledge in her report, and give one reason. 2 marks

End of Topic 3 Test B

Test B — solutions

Q1. (a) **Aim:** "To investigate the effect of adding sugar to the vase water on how long cut flowers last." An aim states the purpose only and predicts nothing. **Hypothesis:** "It is hypothesised that adding sugar to the vase water will increase the number of days that cut flowers last." A hypothesis has to be a **statement** (not a question), about a **measurable** variable, has to commit to a **direction**, and has to be open to being **shown wrong** by the results. (The opposite direction is equally acceptable, provided a direction is given.) *(1 mark: an aim naming both variables and predicting nothing; 1 mark: a testable, direction-giving hypothesis.)*

(b) "Looked fresher" is **not something that can be measured**: it names no quantity, no unit and no instrument, so two people could disagree and no result could show the hypothesis to be wrong. It is also a judgement made by the person who knew which vase held the sugar. A usable dependent variable states **exactly what is counted or measured, in what units and over what period** — for example, **"the number of days until half of the flowers in a vase have wilted"**, or **"the number of petals that have dropped from each flower after seven days"**. *(1 mark: not measurable / subjective / cannot refute the hypothesis; 1 mark: a dependent variable stated precisely enough to measure, with a quantity and a time period.)*

(c) The **two vases hold different species** — six **roses** in the sugar water and six **carnations** in the plain water. The type of flower therefore **changes in step with the treatment**, so **two rival explanations** now fit any difference equally well: the sugar, or simply that roses and carnations last for different lengths of time. Nothing in the results separates them, so **no conclusion about the sugar can be drawn**. *(1 mark: identifies that the two vases contain different species; 1 mark: explains it varies with the treatment, giving an alternative explanation, so no conclusion about the sugar is possible.)*

(d) **Several vases must be set up at each treatment** instead of one — for example, five sugar-water vases and five plain-water vases. (With only one vase in each group, a difference between two single vases cannot be told apart from the ordinary variation between one bunch and another; replicates let the variation be averaged out and an odd vase be spotted.) *(1 mark: use several vases (replicates) per treatment rather than one. No reason is required for this mark.)*

(e) Any **one** controlled variable **other than the one named in part (c)**, for example: the **same number of flowers per vase**; the **same volume of water**; the **same type of vase**; the flowers cut to the **same stem length** and at the **same starting freshness**; the same temperature and light (both already on the one bench). *(1 mark. Do **not** credit the flower species — that is the confounding variable named in part (c), which the stem excludes.)*

Q2. (a) **0 g/L:** (29 + 31 + 30) ÷ 3 = 90 ÷ 3 = **30**; **5 g/L:** (23 + 25 + 24) ÷ 3 = 72 ÷ 3 = **24**; **10 g/L:** (17 + 19 + 18) ÷ 3 = 54 ÷ 3 = **18**; **15 g/L:** (8 + 10 + 9) ÷ 3 = 27 ÷ 3 = **9** seeds. *(1 mark: the 0 and 5 g/L means correct; 1 mark: the 10 and 15 g/L means correct.)*

(b) Percentage = (part ÷ whole) × 100 = (30 ÷ 40) × 100 = **75%**. (The "whole" is the 40 seeds sown in a dish.) *(1 mark.)*

(c) Percentage change = (final − initial) ÷ initial × 100 = (18 − 30) ÷ 30 × 100 = (−12 ÷ 30) × 100 = **−40%** (a **40% decrease**). *(1 mark.)*

(d) The mean at 0 g/L is 30 and at 10 g/L is 18, so the ratio is 30 : 18; dividing both by 6 gives **5 : 3**. *(1 mark.)*

(e) As the salt concentration **increases**, the mean number of seeds germinating **decreases** throughout — a **negative relationship** — falling from **30** at 0 g/L to **9** at 15 g/L, with the steepest fall over the last step (18 to 9). Any figures read from the table earn the mark; a bare "salt affected germination" earns none. *(1 mark: the direction stated in directional language; 1 mark: values quoted from the data to support it.)*

Q3. (a) This is a **personal error** — a mistake in the counting. The slide was not moved, so the number of stomata in that one field of view is a **fixed whole number**; five different answers (31, 28, 33, 29, 30) therefore mean that at least four of the counts are simply **wrong**, because a pore was missed, counted twice, or judged inconsistently at the edge of the field. It is **not a random error**: random error is present in all measurements **except measurements involving counting**, where there is no scale to misjudge. A personal error is not part of an analysis of data quality and is **not** reduced by averaging — it must be **eliminated by doing the count correctly next time**: recount carefully with a fixed rule for pores lying on the edge of the field (for example, count only those touching two chosen sides), using an eyepiece grid to keep her place. *(1 mark: a personal error / a mistake in counting — not a random or systematic* *error; 1 mark: eliminate it by counting again correctly, with a consistent counting rule — averaging cannot fix a mistake.)*

(b) The **area of leaf shown in one field of view is not the same for the two groups**: the ×40 objective shows a **much smaller area** than the ×10 objective, so a count of stomata "per field" means something different for the sun leaves than for the shade leaves. Field area is therefore an **uncontrolled variable that changes with the groups being compared**, so a difference in the counts could be caused by the objective used rather than by sun versus shade. The method does **not measure what it is meant to** — stomata density on a comparable area — so the comparison is **invalid**. *(1 mark: the area sampled differs between the two groups / field area is not controlled; 1 mark: so the counts are not comparable and the difference cannot be attributed to sun vs shade — not valid.)*

(c) Counting several fields per leaf improves the **reliability** of her counts. Stomata are not spread perfectly evenly, so sampling several fields and taking the mean gives a **more consistent and representative** figure for the leaf and **reduces the effect of the natural variation from one part of the leaf to another**, so the result is less likely to depend on a single unusual field. (It does not make an invalid method valid — that is a separate matter.) *(1 mark: reliability; 1 mark: because several samples give a more consistent/representative mean and reduce the effect of the variation between one part of the leaf and another.)*

Q4. (a) As the temperature **increases** from 10 °C to 40 °C, the mean volume of oxygen released **increases**, from about **5 mL** at 10 °C to a **maximum of 27 mL** at 40 °C; **above 40 °C it falls**, dropping to about **10 mL** at 50 °C. The reaction therefore has an **optimum temperature of about 40 °C**. *(1 mark: the rise stated in directional language with start and peak values; 1 mark: the fall after 40 °C, with the 50 °C value / the optimum.)*

(b) A suitable evidence-based conclusion: **"Within the range tested (10–50 °C) and under the conditions of this investigation, the volume of oxygen released by catalase increased as the temperature rose to a maximum at about 40 °C (27 mL) and then decreased at 50 °C (10 mL). These data support the proposal that temperature affects the activity of catalase, with an optimum near 40 °C."** The draft fails because it quotes no data and, by saying only "a higher temperature increases activity", ignores the fall above 40 °C; note also that data **support** a conclusion — they never "prove" it. *(1 mark: answers the aim, giving the direction and the optimum with data; 1 mark: appropriate confidence — bounded to the range tested and these conditions, and not overstated as proof.)*

(c) Any one valid **implication** and any one valid **limitation**, clearly labelled. **Implication** (the wider meaning/use of the finding): for the fastest reaction this enzyme, or a process that uses it, should be run at about 40 °C. **Limitation** (a shortcoming of the design): temperatures were tested only every 10 °C, so the true optimum could lie anywhere between 30 °C and 50 °C; or only one potato source was used; or temperatures above 50 °C were not tested; or only three trials were run at each temperature. *(1 mark: a valid implication, labelled as such; 1 mark: a valid limitation, labelled as such.)*

Q5. (a) The **independent variable** is **which hand is used — the dominant or the non-dominant hand**. The **dependent variable** is the **grip strength measured by the hand-grip meter** (in the meter's units). *(1 mark: IV = dominant vs non-dominant hand; 1 mark: DV = grip strength measured by the meter.)*

(b) Her own hand-grip readings are **primary data**, because she **collects them first-hand** during her own investigation. The published grip-strength figures are **secondary data**, because they are **obtained from someone else's published work** rather than measured by her. *(1 mark: own readings = primary, with reason; 1 mark: published figures = secondary, with reason.)*

(c) Any **one** concept, named, with one action. **Respect** — obtain each volunteer's **informed consent** (explain what is involved) and allow them to **withdraw at any time**; or **non-maleficence** — **avoid harm**, by not letting anyone over-exert and stopping if squeezing causes pain; or **integrity** — record and report **all** the results honestly; or **justice** — select the volunteers **fairly**. *(1 mark: a valid ethical concept named; 1 mark: one action that satisfies it.)*

(d) Any **one** risk to the volunteers, for example: **muscle, tendon or joint strain (or cramp)** in the hand, wrist or forearm from squeezing as hard as possible; **aggravating an existing hand, wrist or arm injury**; a **finger being pinched or crushed** by the meter's handle; **light-headedness** from holding the breath while straining. *(1 mark: one plausible risk to the volunteers. A control measure is not required for this mark.)*

Q6. (a) The **aim and hypothesis** are stated in the **introduction**; the **results table** is placed in the **results** section. *(1 mark: introduction; 1 mark: results.)*

(b) Starting the vertical axis at **20 rather than 0 truncates the axis**, which **exaggerates the difference** between the two groups so that a small real difference looks large, and could **mislead a reader** into thinking the effect is bigger than it is. To present the data honestly she should **start the vertical axis at 0** and use a **full, even scale**, so the true size of the difference is shown. *(1 mark: a truncated / non-zero axis exaggerates the difference and misleads; 1 mark: start the axis at zero with a full, even scale.)*

(c) She must **acknowledge and attribute the knowledge to the specific Aboriginal and/or Torres Strait Islander community or Traditional Owners it belongs to**, citing it as a source in her report as she would any other source, and she must have **used it only with permission and in keeping with cultural protocols**. It is not "common knowledge" that needs no citation. This matters because it **gives proper credit to the knowledge-holders**, **respects their custodianship of that knowledge**, and shows **scientific integrity**. *(1 mark: acknowledge / attribute / cite it to the community or Traditional Owners, used only with permission; 1 mark: one valid reason — credit, respect for custodianship, or integrity.)*