Collecting Data

After designing an investigation that's so beautiful people will marvel at it for years to come, you'll need to get your hands mucky and collect some data.

Your Data Should be as Reliable, Accurate and Precise as Possible

1) To improve reliability you need to repeat the readings and calculate the mean (average). You need to repeat each reading at least three times.
2) To make sure your results are reliable you can cross check them by taking a second set of readings with another instrument (or a different observer).
3) Checking your results match with secondary sources, e.g. other studies, also increases the reliability of your data.
4) Your data also needs to be ACCURATE. Really accurate results are those that are really close to the true answer.
5) Your data also needs to be PRECISE. Precise results are ones where the data is all really close to the mean (i.e. not spread out).

Repeat	Data set 1	Data set 2
1	12	11
2	14	17
3	13	14
Mean	13	14

Data set 1 is more precise than data set 2.

Your Equipment has to be Right for the Job

1) The measuring equipment you use has to be sensitive enough to measure the changes you're looking for. For example, if you need to measure changes of 1 ml you need to use a measuring cylinder that can measure in 1 ml steps — it'd be no good trying with one that only measures 10 ml steps.
2) The smallest change a measuring instrument can detect is called its RESOLUTION. E.g. some mass balances have a resolution of 1 g, some have a resolution of 0.1 g, and some are even more sensitive.
3) Also, equipment needs to be calibrated so that your data is more accurate. E.g. mass balances need to be set to zero before you start weighing things.

You Need to Look out for Errors and Anomalous Results

1) The results of your experiment will always vary a bit because of random errors — tiny differences caused by things like human errors in measuring.
2) You can reduce their effect by taking many readings and calculating the mean.
3) If the same error is made every time, it's called a SYSTEMATIC ERROR. For example, if you measured from the very end of your ruler instead of from the 0 cm mark every time, all your measurements would be a bit small.
4) Just to make things more complicated, if a systematic error is caused by using equipment that isn't calibrated properly it's called a ZERO ERROR. For example, if a mass balance always reads 1 gram before you put anything on it, all your measurements will be 1 gram too heavy.
5) You can compensate for some systematic errors if you know about them though, e.g. if your mass balance always reads 1 gram before you put anything on it you can subtract 1 gram from all your results.
6) Sometimes you get a result that doesn't seem to fit in with the rest at all.
7) These results are called ANOMALOUS RESULTS.
8) You should investigate them and try to work out what happened. If you can work out what happened (e.g. you measured something totally wrong) you can ignore them when processing your results.

Repeating the experiment in the exact same way and calculating an average won't correct a systematic error.

Park	Number of pigeons	Number of crazy tramps
A	28	1
B	42	2
C	1127	0

Zero error — sounds like a Bruce Willis film...

Weirdly, data can be really precise but not very accurate, e.g. a fancy piece of lab equipment might give results that are precise, but if it's not calibrated properly those results won't be accurate.

Designing Investigations

Dig out your lab coat and dust down your badly-scratched safety goggles... it's investigation time. You need to know a shed load about investigations for your controlled assessment and all your exams. Investigations include experiments and studies. The next six pages take you from start to finish. Enjoy.

Investigations Produce Evidence to Support or Disprove a Hypothesis

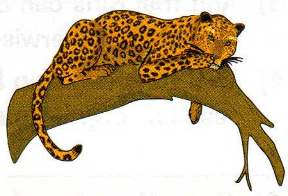
1) Scientists observe things and come up with hypotheses to explain them (see page 1).
2) To figure out whether a hypothesis might be correct or not you need to do an investigation to gather some evidence.
3) The first step is to use the hypothesis to come up with a prediction — a statement about what you think will happen that you can test.
4) For example, if your hypothesis is:

   "Spots are caused by picking your nose too much."

   Then your prediction might be:

   "People who pick their nose more often will have more spots."
5) Investigations are used to see if there are patterns or relationships between two variables. For example, to see if there's a pattern or relationship between the variables 'having spots' and 'nose picking'.
6) The investigation has to be a FAIR TEST to make sure the evidence is reliable and valid...

Sometimes the words 'hypothesis' and 'prediction' are used interchangeably.



See page 2 for more on reliability and validity.

To Make an Investigation a Fair Test You Have to Control the Variables

1) In a lab experiment you usually change one variable and measure how it affects the other variable.

   EXAMPLE: you might change only the temperature of a chemical reaction and measure how this affects the rate of reaction.
2) To make it a fair test everything else that could affect the results should stay the same (otherwise you can't tell if the thing you're changing is causing the results or not — the data won't be reliable or valid).

   EXAMPLE continued: you need to keep the concentration of the reactants the same, otherwise you won't know if any change in the rate of reaction is caused by the change in temperature, or a difference in reactant concentration.
3) The variable you CHANGE is called the INDEPENDENT variable.
4) The variable you MEASURE is called the DEPENDENT variable.
5) The variables that you KEEP THE SAME are called CONTROL variables.

   EXAMPLE continued:
   Independent variable = temperature
   Dependent variable = rate of reaction
   Control variables = concentration of reactants, volume of reactants, etc.

Designing Investigations

Trial Runs help Figure out the Range and Interval of Variable Values

1) It's a good idea to do a trial run first — a quick version of your experiment.
2) Trial runs are used to figure out the range of variable values used in the proper experiment (the upper and lower limit). If you don't get a change in the dependent variable at the lower values in the trial run, you might narrow the range in the proper experiment. But if you still get a big change at the upper values you might increase the range.

EXAMPLE continued:

- You might do a trial run with a range of 10-50 °C. If there was no reaction at the lower end (e.g. 10-20 °C), you might narrow the range to 20-50 °C for the proper experiment.
- If using 1 °C intervals doesn't give you much change in the rate of reaction each time you might decide to use 5 °C intervals, e.g 20, 25, 30, 35, 40, 45, 50 °C...

3) And trial runs can be used to figure out the interval (gaps) between the values too. The intervals can't be too small (otherwise the experiment would take ages), or too big (otherwise you might miss something).
4) Trial runs can also help you figure out how many times the experiment has to be repeated to get reliable results. E.g. if you repeat it three times and the results are all similar, then three repeats is enough.

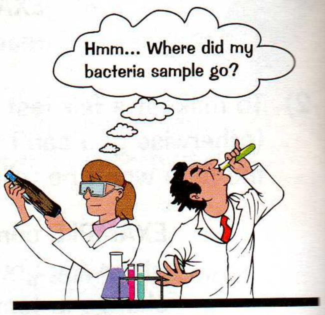
It Can Be Hard to Control the Variables in a Study

It's important that a study is a fair test, just like a lab experiment. It's a lot trickier to control the variables in a study than it is in a lab experiment though (see previous page). Sometimes you can't control them all, but you can use a control group to help. This is a group of whatever you're studying (people, plants, lemmings, etc.) that's kept under the same conditions as the group in the experiment, but doesn't have anything done to it.

EXAMPLE: If you're studying the effect of pesticides on crop growth, pesticide is applied to one field but not to another field (the control field). Both fields are planted with the same crop, and are in the same area (so they get the same weather conditions). The control field is there to try and account for variables like the weather, which don't stay the same all the time, but could affect the results.

Investigations Can be Hazardous

1) A hazard is something that can potentially cause harm. Hazards include:
   - Microorganisms, e.g. some bacteria can make you ill.
   - Chemicals, e.g. sulfuric acid can burn your skin and alcohols catch fire easily.
   - Fire, e.g. an unattended Bunsen burner is a fire hazard.
   - Electricity, e.g. faulty electrical equipment could give you a shock.



2) Scientists need to manage the risk of hazards by doing things to reduce them. For example:
   - If you're working with sulfuric acid, always wear gloves and safety goggles. This will reduce the risk of the acid coming into contact with your skin and eyes.
   - If you're using a Bunsen burner, stand it on a heat proof mat. This will reduce the risk of starting a fire.

You can find out about potential hazards by looking in textbooks, doing some internet research, or asking your teacher.

You won't get a trial run at the exam, so get learnin'...

All this info needs to be firmly lodged in your memory. Learn the names of the different variables — if you remember that the variable you chaNge is called the iNdependent variable, you can figure out the other ones.

Processing and Presenting Data

After you've collected your data you'll have oodles of info that you have to make some kind of sense of. You need to process and present it so you can look for patterns and relationships in it.

Data Needs to be Organised

1) Tables are dead useful for organising data.
2) When you draw a table use a ruler, make sure each column has a heading (including the units) and keep it neat and tidy.
3) Annoyingly, tables are about as useful as a chocolate teapot for showing patterns or relationships in data. You need to use some kind of graph for that.

You Might Have to Process Your Data

1) When you've done repeats of an experiment you should always calculate the mean (average). To do this ADD TOGETHER all the data values and DIVIDE by the total number of values in the sample.
2) You might also need to calculate the range (how spread out the data is). To do this find the LARGEST number and SUBTRACT the SMALLEST number from it.

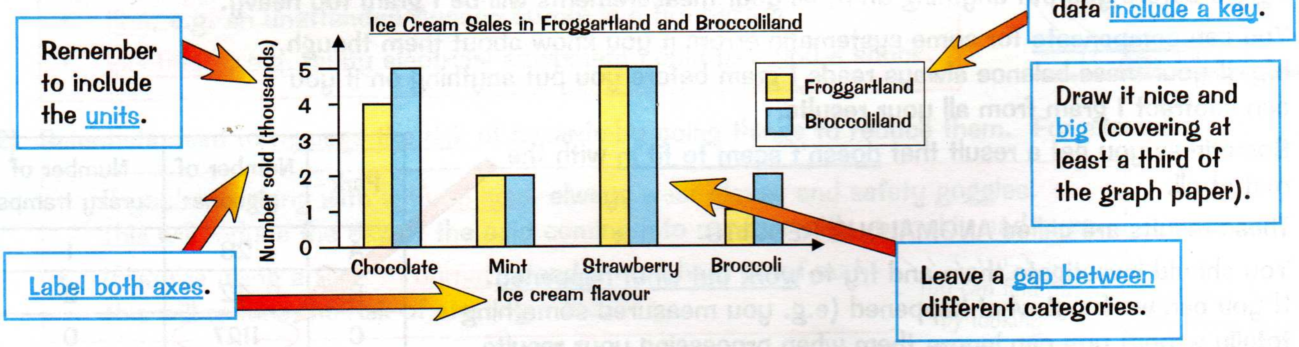
Ignore anomalous results when calculating these.

EXAMPLE

Test tube	Repeat 1 (g)	Repeat 2 (g)	Repeat 3 (g)	Mean (g)	Range (g)
A	28	37	32	(28 + 37 + 32) ÷ 3 = 32.3	37 − 28 = 9
B	47	51	60	(47 + 51 + 60) ÷ 3 = 52.7	60 − 47 = 13
C	68	72	70	(68 + 72 + 70) ÷ 3 = 70.0	72 − 68 = 4

If Your Data Comes in Categories, Present It in a Bar Chart

1) If the independent variable is categoric (comes in distinct categories, e.g. blood types, metals) you should use a bar chart to display the data.
2) You also use them if the independent variable is discrete (the data can be counted in chunks, where there's no in-between value, e.g. number of people is discrete because you can't have half a person).
3) There are some golden rules you need to follow for drawing bar charts:



Discrete variables love bar charts — although they'd never tell anyone that...

The stuff on this page might all seem a bit basic, but it's easy marks in the exams (which you'll kick yourself if you don't get). Examiners are a bit picky when it comes to bar charts — if you don't draw them properly they won't be happy. Also, double check any mean or range calculations you do, just to be sure they're correct.

Presenting Data

Scientists just love presenting data as line graphs (weirdos)...

If Your Data is Continuous, Plot a Line Graph

1) If the independent variable is continuous (numerical data that can have any value within a range, e.g. length, volume, temperature) you should use a line graph to display the data.
2) Here are the rules for drawing line graphs:

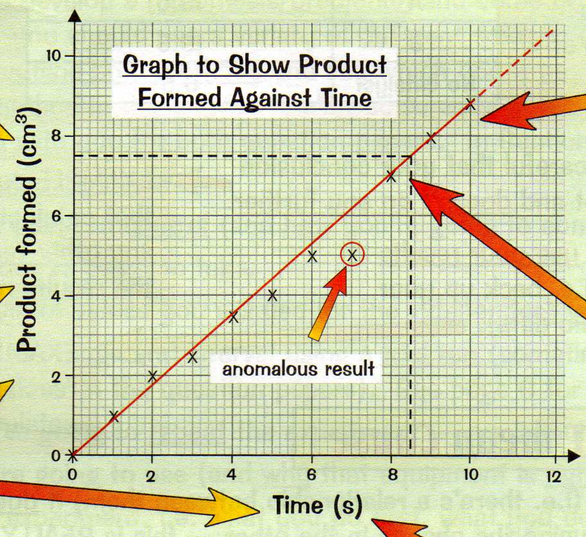
Remember to include the units.

Put the dependent variable (the thing you measure) on the y-axis (the vertical one).

Label both axes.

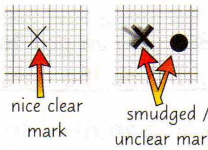
If you've got more than one set of data include a key.

Draw it nice and big (covering at least a third of the graph paper).



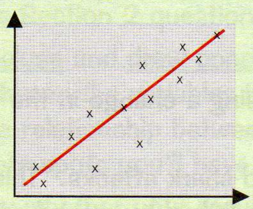
Put the independent variable (the thing you change) on the x-axis (the horizontal one).

To plot the points, use a sharp pencil and make a neat little cross (don't do blobs).

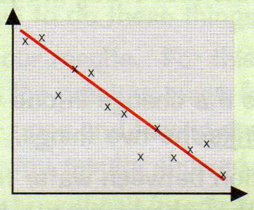


Don't join the dots up. You need to draw a line of best fit (or a curve of best fit if your points make a curve). When drawing a line (or curve), try to draw the line through or as near to as many points as possible, ignoring anomalous results.

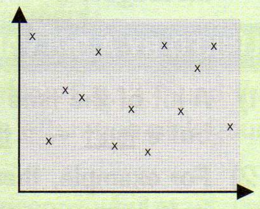
3) Line graphs are used to show the relationship between two variables (just like other graphs).
4) Data can show three different types of correlation (relationship):



POSITIVE correlation — as one variable increases the other increases.



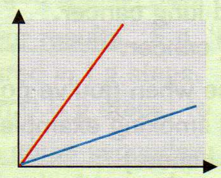
NEGATIVE correlation — as one variable increases the other decreases.



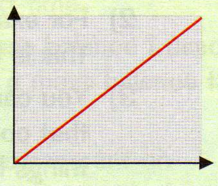
NO correlation — there's no relationship between the two variables.

5) You need to be able to describe the following relationships on line graphs too:

LINEAR — the graph is a straight line.



DIRECTLY PROPORTIONAL — the graph is a straight line where both variables increase (or decrease) in the same ratio.



There's a positive correlation between revision and boredom...

...but there's also a positive correlation between revision and getting a better mark in the exam. Cover the page and write down the eight things you need to remember when drawing graphs. No sneaky peeking either — I saw you.

Drawing Conclusions

Congratulations — you've made it to the final step of a gruelling investigation — drawing conclusions.

You Can Only Conclude What the Data Shows and NO MORE

1) Drawing conclusions might seem pretty straightforward — you just look at your data and say what pattern or relationship you see between the dependent and independent variables.

EXAMPLE: The table on the right shows the rate of a reaction in the presence of two different catalysts.

Catalyst	Rate of reaction (cm^3/s)
A	13.5
B	19.5
No catalyst	5.5

CONCLUSION: Catalyst B makes this reaction go faster than catalyst A.

2) But you've got to be really careful that your conclusion matches the data you've got and doesn't go any further.

EXAMPLE continued: You can't conclude that catalyst B increases the rate of any other reaction more than catalyst A — the results might be completely different.

3) You also need to be able to use your results to justify your conclusion (i.e. back up your conclusion with some specific data).

EXAMPLE continued: The rate of this reaction was 6 cm^3/s faster using catalyst B compared with catalyst A.

Correlation DOES NOT mean Cause

1) If two things are correlated (i.e. there's a relationship between them) it doesn't necessarily mean that a change in one variable is causing the change in the other — this is REALLY IMPORTANT, DON'T FORGET IT.
2) There are three possible reasons for a correlation:

1 CHANCE

1) Even though it might seem a bit weird, it's possible that two things show a correlation in a study purely because of chance.
2) For example, one study might find a correlation between people's hair colour and how good they are at frisbee. But other scientists don't get a correlation when they investigate it — the results of the first study are just a fluke.

2 LINKED BY A 3rd VARIABLE

1) A lot of the time it may look as if a change in one variable is causing a change in the other, but it isn't — a third variable links the two things.
2) For example, there's a correlation between water temperature and shark attacks. This obviously isn't because warmer water makes sharks crazy. Instead, they're linked by a third variable — the number of people swimming (more people swim when the water's hotter, and with more people in the water you get more shark attacks).

3 CAUSE

1) Sometimes a change in one variable does cause a change in the other.
2) For example, there's a correlation between smoking and lung cancer. This is because chemicals in tobacco smoke cause lung cancer.
3) You can only conclude that a correlation is due to cause when you've controlled all the variables that could, just could, be affecting the result. (For the smoking example above this would include things like age and exposure to other things that cause cancer).

I conclude that this page is a bit dull...

...although, just because I find it dull doesn't mean that I can conclude it's dull (you might think it's the most interesting thing since that kid got his head stuck in the railings near school). In the exams you could be given a conclusion and asked whether some data supports it — so make sure you understand how far conclusions can go.

Controlled Assessment (ISA)

Controlled Assessment involves doing an experiment and answering two question papers on it under exam conditions. Sounds thrilling.

There are Two Sections in the Controlled Assessment

1 Planning

Before you do the Section 1 question paper you'll be given time to do some research into the topic that's been set — you'll need to develop a hypothesis/prediction and come up with two different methods to test it. In your research, you should use a variety of different sources (e.g. the internet, textbooks etc.). You'll need to be able to outline both methods and say which one is best (and why it's the best one) and describe your preferred method in detail. You're allowed to write notes about your two methods on one side of A4 and have them with you for both question papers. In Section 1, you could be asked things like:

1) What your hypothesis/prediction is.
2) What variables you're going to control (and how you're going to control them).
3) What measurements you're going to take.
4) What range and interval of values you will use for the independent variable.
5) How you'd figure out the range and interval using a trial run (sometimes called a 'preliminary investigation' in the question papers). See page 6 for more.
6) How many times you're going to repeat the experiment — a minimum of three is a good idea.
7) What equipment you're going to use (and why that equipment is right for the job).
8) How to carry out the experiment, i.e. what you do first, what you do second...
9) What hazards are involved in doing the experiment, and how to reduce them.
10) What table you'll draw to put your results in. See page 8 for how to draw one that examiners will love.

There's lots of help on all of these things on pages 5-10.

When you've done the planning and completed the first question paper you'll actually do the experiment. Then you'll have to present your data. Make sure you use the right type of graph, and you draw it properly — see pages 8-9 for help. After that it's onto the Section 2 question paper...

2 Drawing Conclusions and Evaluating

For the Section 2 question paper you have to do these things for your experiment:

1) Analyse and draw conclusions from your results. For this you need to describe the relationship between the variables in detail — see the previous page for how to do this. E.g. 'I found that there is a relationship between picking your nose and having spots. The more often you pick your nose the more spots you'll have. For example, my results showed...'.
2) Say whether your results back up the hypothesis/prediction, and give reasons why or why not. E.g. 'My results did not back up the prediction. The prediction was that picking your nose more has no effect on the number of spots you have. But I found the opposite to be true in my investigation'.
3) Evaluate your experiment. For this you need to suggest ways you could improve your experiment.
   - Comment on your equipment and method, e.g. could you have used more accurate equipment?
   - Make sure you explain how the improvements would give you better data next time.
   - Refer to your results. E.g. 'My data wasn't accurate enough because the mass balance I used only measured in 1 g steps. I could use a more sensitive one next time (e.g. a mass balance that measures in 0.5 g steps) to get more accurate data'.

You'll also be given some secondary data (data collected by someone else) from an experiment on the same topic and asked to analyse it. This just involves doing what you did for your data with the secondary data, e.g. draw conclusions from it.

If that's controlled assessment, I'd hate to see uncontrolled assessment...

That might be an Everest-sized list of stuff, but it's all important. No need to panic at the sight of it though — as long as you've learnt everything on the previous few pages, you should be fine.