Research question: What do you want to find out?

I would like to find out how (independent variable/x) affects the (dependent variable/y)

Introduction: This should include (as appropriate):

- The name of the species studied, preferably binomial.
- Consideration of the ethics of your experiment e.g. research into the tolerance limits of the animal, consent form (if necessary to determine health of subject)
- A description of the reaction or process e.g. movement from where to where ..through what… how far.
- If your measurement of a variable is indirect, explain the link e.g. pressure due to build-up of gas ….
- Research into the possible outcome of the experiment. Include citation and bibliography.

Variables: Start with the first two columns

Variable	Independent/Dependent Control	Value*	Strategy for altering, measuring or controlling

* You won't be able to complete this for all variables!

Method :

1. Before you start writing your method decide how you are going to analyse your data!

- Looking for an increase or a decrease: Do you need to carry out a control experiment?
- Looking for a trend: You will need to collect enough data to draw a graph. AT LEAST five values with as many repeats as is possible in the time available.

Trend Box

Draw lines of best fit, and identify: Inversely proportional .. 'S' shaped… directly proportional … optimum

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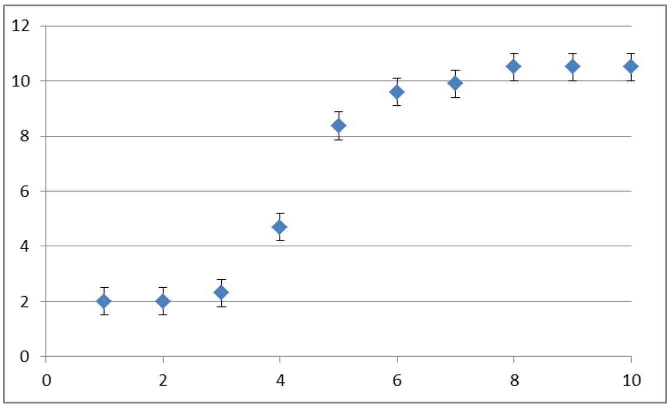

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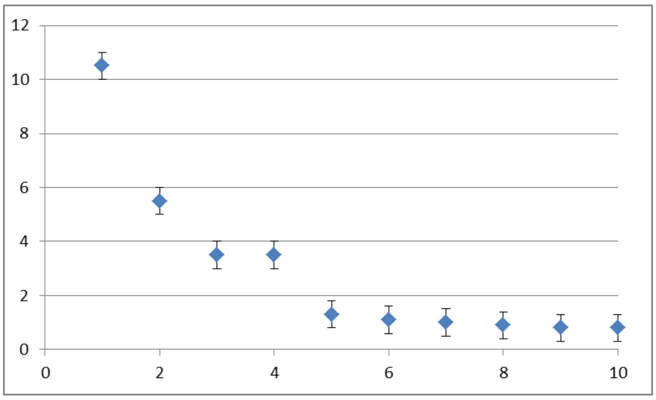

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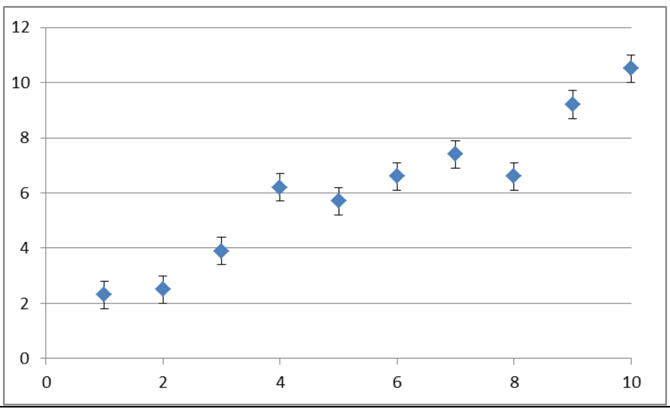

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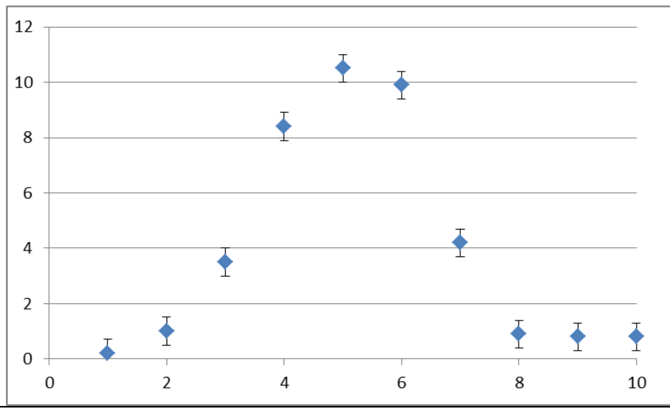


- Looking for a difference: Will you calculate a standard deviation and a t-test? You will need a minimum sample size of at least 10 for each data set.

2. Write your method

- Use planning playtime to complete your selection of variables table, and choose suitable measuring apparatus
- Write a set of instructions that could be followed by a stranger. Make sure you take safety into account.
- Draw a large diagram, but only if it helps you to explain.
- Plan to use all of the time available.
- Do you need to allow time for organisms/chemicals reach starting conditions?

Apparatus: a list of the apparatus and materials you need.

- Estimate **quantities** required. Use the minimum in order to minimise the environmental impact of your experiment.
- Give **concentration** of stock solution to be used [mol dm^{-3}]. You will have to dilute this yourself if you want to investigate concentration.
- Specify **size** of glassware. 50 cm^3 beaker rather than 'beaker'. Is it appropriate? (e.g. measuring cylinder rather than beaker to measure 100 cm^3 liquid). Think about minimising sources of error!
- Include apparatus to measure your dependent, independent **AND** control variables!

Data collection:

Include quantitative AND qualitative data!!

Data Presentation Box

Title

Table to show the results of an investigation into the effects of light on the movement of chloroplasts in leaf epidermal cells

Variable in the column heading.

Diagonal line... then unit.

Uncertainty/accuracy of measuring devices (± ......)

Light intensity / K lux (±.01)	Time taken to move 25 μm / seconds (± 0.01)		Mean time taken to move 25 μm / seconds (± 0.01)
	Trial one	Trial two	
1.20	12.10	11.93	11.96
1.50	7.40	7.55	11.25
1.90	7.33	7.40	11.03
2.00	7.30	7.15	10.88
2.50	7.00	7.00	7.00

Independent variable in first column, arranged in **ascending order**.

Never include units in body of table. Numbers with decimal points in line.

A final column can be added for processed data. **Use correct number of significant figures.**

This sort of table is great for collecting data, but you would need to draw another table to show the differences and the means!

Concentration /m dm^{-3} (±.01)	Time of reading	Mass of sample / g (± 0.1)	
		Trial one	Trial two
1.20	Initial	6.8	7.2
	Final	7.0	7.4
1.50	Initial	7.4	7.6
	Final	7.5	7.8
1.90	Initial	7.3	7.4
	Final	7.5	7.6
2.00	Initial	7.7	7.1
	Final	7.9	7.5
2.50	Initial	7.0	7.0
	Final	7.2	7.4

Tables can also be arranged horizontally if this saves space:

Concentration of salt solution/ m dm^{-3} (± 0.005)	0.00	0.01	0.03	0.05	0.07	0.09	0.50	1.00
Colorimeter reading / % transmission (± 1)	2	25	25	25	50	55	62	42

Quick fixes: Make sure that

- that your table has a title including both dependent and independent variables.
- all time measurements are given in seconds.
- you include uncertainties. (these may be greater than the precision of the instrument!)
- there is a match between the uncertainty and the precision of measurements.
- you include subscripts and superscripts.
- you record qualitative data too!!!

Data Processing and Presentation

- CARE! If you are looking for a change, do you need to calculate a difference? or a percentage?
- Can you calculate a rate? e.g. speed/μm $second^{-1}$ OR gm cm^{-3}
- Would calculating a standard deviation or carrying out a T test be helpful? (explain)
- Presenting your calculations: Include a sample calculation. Show all steps clearly, explaining the method.
- Have you kept the correct number of significant figures?
- Summarise the results of your calculations in a table, spread sheet, flowchart or graph.
- Make sure this has clear a title that includes both input and output variables.

Plotting graphs (If you are interested in an increase or decrease, NEVER plot the raw results!!)

By hand: Make sure that ….

- The independent (x) variable is on the x axis.
- Your axes are labelled with the name of the variable, the units AND the uncertainty.
- You choose a decimal scale which is easy to use (e.g. NOT 3 squares = 10)
- Make your graph as big as possible. You don't have to include zero on either axis!
- You plot points as crosses. Use a sharp pencil for accuracy.
- If you draw a line of best fit/regression line. DON'T simply joint up the points. Do this as a scientist as you will need to justify this in your conclusion.

Using Excel: Do not automatically use default settings e.g.

- Trial one/trial two NOT series one/series two..
- Justify your choice of error bar.
- Choose appropriate axis dimensions.
- Don't always let Excel to insert your trend line.

Scatter graphs: Used for trends. This shows the spread of results. Plot a regression line.

Graph of means: Used for trends. Include bars to show uncertainty/sd/range of data.Plot a regression line.

Bar graph: Used for differences. Include bars to show sd or range of data.

Conclusion and Evaluation

Part One: Evaluating the procedure:

- Were your results **reliable** (would you get the same results if you did it again/ did you carry out enough repeats?) Explain.
- Were your results **valid** / was it a fair test? Identify any variables which weren't properly controlled … Explain how could this have affected your results (direction & magnitude).
- Did you carry out an appropriate **range** of measurements? (maximum/minimum/intermediates)
- Discuss the sources of **uncertainty**. (instrument / estimation uncertainties / choice of apparatus)
- Discuss your **time management** and **organisation**.

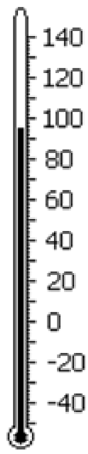
Part Two: Drawing conclusions from your results:

- Describe and compare any significant **trends** or **patterns** in your results.
- Justify this by giving a scientific (causal) explanation of your results, or referring to other similar studies or literature values.
- Can you **extrapolate** the data to suggest whether/where the trend line would intercept the x or y axis?
- … or comment on maximum or minimum values?
- Include a bibliography at the end of your investigation.

Part Three: Suggesting Improvements:

- Go over each of the problems identified in part one, and suggest how these problems could be solved.
- Be specific. Data logger rather than 'more precise equipment'.
- Would additional repeats have helped? Helpful if there are random uncertainties, but not systematic errors.
- Could a further experiment help you answer your **original** research question?

Error and Uncertainty box



1. Recording uncertainty
   a. What temperature is shown by the thermometer?
   b. Which temperature should we record? ....
   c. What is the uncertainty? ± ....°C

2. Calculating Error

Reading	Temperature /°C (± 0.1)		Temperature /°C (± 0.2)	
	Experiment 1	Experiment 2	Experiment 3	Experiment 4
Initial	30.0	30	21.8	21.5
Final	32.0	32	24.2	21.6
Difference:				
Error:				

   i. **Explain** the differences between the uncertainties in the four experiments.
   ii. For which experiments would systematic error be a problem?
   iii. **Suggest** how these experiments could be improved.

3. Significant Figures in Science
   a. **Determine** the number of significant figures in the following measurements:
      i. 23g ii. 0.023kg iii. 0.230kg
      iv. 0.0203kg v. 202.999kg vi. 203.000kg
   b. Give the uncertainty of each of the measurements below:

Length/metres	Significant figures	Uncertainty
2 600		
3×10^3		
2.6×10^3		
2.60×10^3		
2.600×10^3		

   c. Calculating with uncertainties

After calculation, the answer should be 'rounded off' to keep only the same number of decimal places as the least precise item. It is best to do this at the end of a calculation!

(i)	(ii)	(iii)	(iv)
46.24	26.6	2.4	203
3.219	0.0028	3.6584	4
0.224 +	0.00002 +	0.029 +	0.77 +

Calculating error for an anomalous result:

a. Observed result (from results table). 1.50 kilolux: 0.296 µm sec^{-1}
b. Expected result (from graph or literature) 0.336 µm sec^{-1}
c. Error = observed – expected 0.336 - 0.296 = 0.040 µm sec^{-1}
d. Percentage error: (observed – expected / expected) x 100 $\frac{0.336 - 0.296}{0.296} \times 100 = 14\%$

Could the error due to the precision of the measuring instruments?

Add together the % uncertainties e.g.:

Luxmeter / lux (± 0.01): 1.5 (0.01/1.5) x 100 = 0.07%
Stopwatch/ seconds (± 0.01): 7.55 (0.01/7.55) x 100 = 0.1%
Distance travelled / µm (± 1):25 (1/25) x100 = 4% total = 4.1%

Design

Marks	Defining the problem and selecting variables	Controlling variables	Developing a method for collection of data
C/2	Formulates a focused problem/ research question and identifies the relevant variables.	Designs a method for the effective control of the variables	Develops a method that allows for the collection of sufficient relevant data.
P/1	Formulates a problem/research question that is incomplete or identifies only some relevant variables.	Designs a method that makes some attempt to control the variables.	Develops a method that allows for the collection of insufficient relevant data.
N/0	Does not identify a problem/ research question and does not identify any relevant variables.	Designs a method that does not control the variables.	Develops a method that does not allow for any relevant data to be collected.

Data collection and processing

Marks	Recording raw data	Processing raw data	Presenting processed data
C/2	Records appropriate quantitative and associated qualitative raw data, including units and uncertainties where relevant.	Processes the quantitative raw data correctly.	Presents processed data appropriately and, where relevant, includes errors and uncertainties.
P/1	Records appropriate quantitative and associated qualitative raw data, but with some mistakes or omissions.	Processes quantitative raw data, but with some mistakes and/or omissions.	Presents processed data appropriately, but with some mistakes and/or omissions.
N/0	Does not record any appropriate quantitative raw data or raw data is incomprehensible.	No processing of quantitative raw data is carried out or major mistakes are made in processing.	Presents processed data inappropriately or incomprehensibly.

Conclusion and evaluation

Marks	Concluding	Evaluating procedure(s)	Improving the investigation
C/2	States a conclusion, with justification, based on a reasonable interpretation of the data.	Evaluates weaknesses and limitations.	Suggests realistic improvements in respect of identified weaknesses and limitations.
P/1	States a conclusion based on a reasonable interpretation of the data.	Identifies some weaknesses and limitations, but the evaluation is weak or missing.	Suggests only superficial improvements.
N/0	States no conclusion or the conclusion is based on an unreasonable interpretation of the data.	Identifies irrelevant weaknesses and limitations.	Suggests unrealistic improvements.

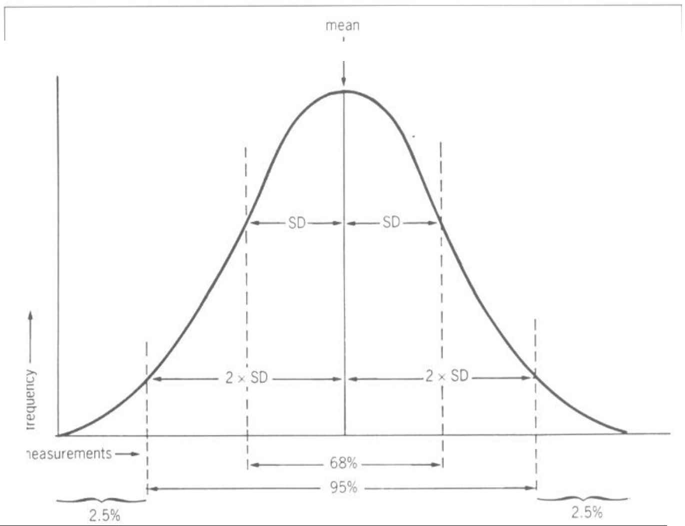
Manipulative skills (assessed summatively)

Marks	Following instructions*	Carrying out techniques	Working safely
C/2	Follows instructions accurately, adapting to new circumstances (seeking assistance when required).	Competent and methodical in the use of a range of techniques and equipment.	Pays attention to safety issues.
P/1	Follows instructions but requires assistance.	Usually competent and methodical in the use of a range of techniques and equipment.	Usually pays attention to safety issues.
N/0	Rarely follows instructions or requires constant supervision.	Rarely competent and methodical in the use of a range of techniques and equipment.	Rarely pays attention to safety issues.

Statistics

The term standard deviation can only be used with a normal or near normal distribution. It is used to summarize the spread of values around the mean and that 68% of all values fall within ± standard deviation of the mean. This rises to about 95% for ±2 standard deviations.

$$SD = \sqrt{\frac{\sum d^2}{n}}$$



Sample No	Variable / unit (±…..)	Mean Variable / unit (±…..)	Deviation (d) from mean	d^2
			$\sum d^2$=	

t-test

Google: t-test calculator

http://www.graphpad.com/quickcalcs/ttest1.cfm

Degrees of freedom	Significance level				
	20%	10%	**5%**	2%	1%
14	1.34	1.76	**2.14**	2.62	2.98
15	1.34	1.75	**2.13**	2.60	2.95
16	1.33	1.75	**2.12**	2.58	2.92
17	1.33	1.74	**2.11**	2.57	2.90
18	1.33	1.73	**2.10**	2.55	2.88
19	1.32	1.73	**2.09**	2.54	2.86
20	1.32	1.73	**2.09**	2.53	2.85
21	1.32	1.72	**2.08**	2.52	2.83
22	1.32	1.72	**2.07**	2.51	2.82
23	1.31	1.71	**2.07**	2.50	2.81
24	1.31	1.71	**2.06**	2.49	2.80
25	1.31	1.71	**2.06**	2.49	2.79
26	1.31	1.71	**2.06**	2.48	2.78
27	1.31	1.70	**2.05**	2.47	2.77
28	1.31	1.70	**2.05**	2.47	2.76
29	1.31	1.70	**2.04**	2.46	2.76
30	1.31	1.70	**2.04**	2.46	2.75
40	1.30	1.68	**2.02**	2.42	2.70
50	1.30	1.67	**2.00**	2.40	2.67
60	1.29	1.67	**2.00**	2.39	2.66
120	1.28	1.65	**1.98**	2.15	2.61

Degrees of freedom = (sample 1 + sample 2) – 2

Merson-Davies A. (2008) Study Guide for IA in Biology. Fleet Litho, Tunbridge Wells

Apparatus and Materials Menu