

Research Question as title**Background**

- Separate your background with subheadings for clarity
- Provide context for your RQ (disturbance, climate change, pollution, improving process, culture, etc.)
- The reader should understand *why* you are doing this study, why it's important – it should clearly convey personal interest and try to include local issues (if possible)
- Explain clearly any scientific theory/information relevant to your study of which the reader should be made aware
- Explain and justify your *study species* – why is this species being used to investigate your RQ?
- Describe prior studies that have conducted a similar experiment and outline their findings
- Explain why is your study novel/different than past investigations. If your study has already been done, explain what new aspect your investigation is bringing to the literature/topic (extensions, etc.)

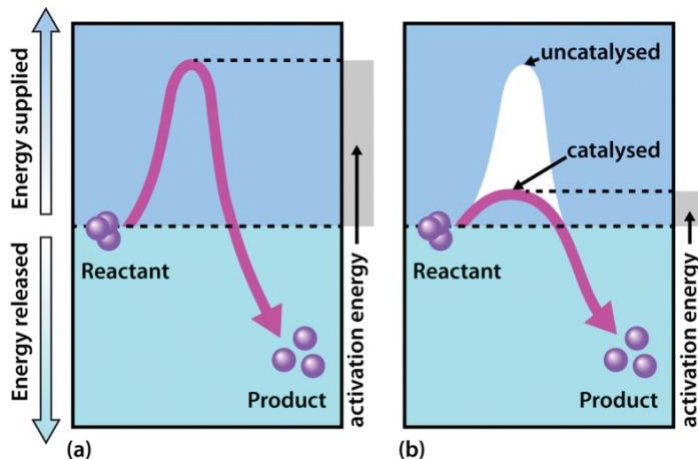


Figure 1 Effect of an enzyme on reducing the activation energy required to start a reaction (Robinson, 2015)

* When pictures are used, include a picture caption. If you didn't make the picture/diagram, reference its use (figure 1). Ensure it is cited in your body and the figure is close to where it is being referenced.

* Entire section should be heavily supported with multiple, different, relevant scientific citations (scientific papers) and cited in a consistent format in-text (scientific, MLA, Chicago, etc.)

* Search <https://scholar.google.com/> using your chosen topic/variables to find and read relevant studies and use <https://sci-hub.se/> to find full papers for free!

Aim of Investigation

- Provide a brief explanation of what you are going to do in your investigation, i.e. what is your goal?

Research Question

- One-sentence research question. Should be specific and concise and contain the IV (with range), DV (with units of measure and time period of measure) and species name (if applicable). The reader should know very clearly what you are investigating
- The research question needs be able to be answered by a clear hypothesis

Ex: How do different concentrations of the sulfonamide antibiotic, Co-trimoxazole [SMX/TMP], (10.0, 20.0, 30.0, 40.0, 50.0 mg mL⁻¹) affect the initial growth of *Oryza sativa* (rice) seeds as measured in by changes in their radicle (root) and hypocotyl (shoot) length (cm) after 7 days?

Hypothesis

- **Hypothesis:** Provide a clear, concise, measurable hypothesis i.e. answer your RQ. This could be supported with a general graph of what you think the relationship will be (figure 2)
- **Justification:** Provide a clear explanation of why you think this will occur. This is supported by scientific papers/prior studies/biological theory and should be referenced

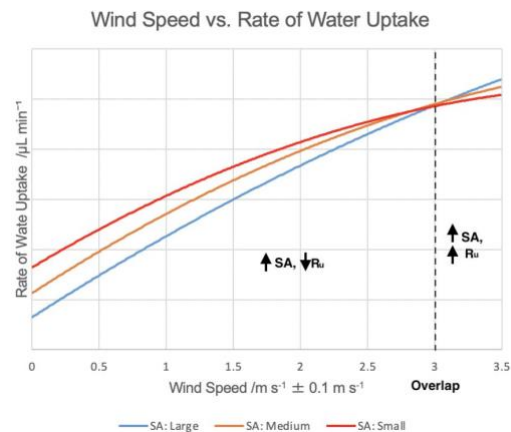


Figure 2 Graphical representation of hypothesis, portraying wind speed against rate of water uptake with different leaf sizes

Independent Variable

- List the experimental groups (including units if applicable)

Ex: concentration (mol/L), pH, temperature (°C), reaction time(s), surface area (cm²), ratio x:y...

- Justify why these (range, quantity, increments) were chosen. Can be adapted from prior studies
- How will this be manipulated?
- How many repeats/trials per IV group? Justify this choice.

* Aim for 4 IV groups + 1 control group (5 IV groups in total). Aim for 5 trials/repeats at minimum per IV group. Ideally do more, especially for a DV like germination where you can do A LOT

Dependent Variable

- State what it is (including units and time period of measure, if applicable)

Ex: change in temperature (°C)/ mass (g)/ height (cm)/pH, gas produced (mL), absorbance (Au), yield (g), conductivity (Amp), voltage (V), heart/respiratory rate (BPM), area of growth (mm²), concentration (mol/mL)...

- *Must be quantitative*
- Describe how it will be measured and over what time period including apparatus
- Justify this choice (why this measurement, quantity, time etc.). Can be adapted from prior studies.

* Strong justifications for your variables provide the reader with confidence as to the methodological design.

Control Variables

- Include this as a table:

Variable	Impact	Method of Control
Specific name of the variable	Explain what is the potential/likely impact this could have on results, i.e. why is it important to control. Provide scientific references	How will this be controlled / kept constant. Include specific apparatus and values. Should also be justified and with references for support

* DO NOT break a table over multiple pages, keep it on one page.

Risk Management

- Describe what the potential risks/hazards are in your method and how you will prevent these. Good references to use: [CLEAPSS](#), [chemicalsafety](#) [MSDS](#) Should be presented as a table:

Hazard	Nature of the Hazard	Control
Name of the hazard. Can be chemical, microorganism, hazardous procedure or equipment	The potential harm or risk this hazard poses to the investigator. Support this with references.	How will this be controlled so as to minimize/eliminate risk? These should directly link to the hazards listed. Support this with references.

Ethical/Environmental Considerations

- Explain how your investigation may cause ethical (if living subjects are involved) or environmental (such as disposal or disturbance) concerns and how these were minimized/mitigated or prevented (if possible)

** This section is required whether or not you think your method is 'safe' or not.*

Materials and Apparatus

- Present as a list (columns if necessary for space saving)
- Each material should be followed by an amount (with units) and quantity (if relevant)
- Each apparatus/measuring instrument should be followed by the unit in which it measures and an uncertainty (examples: 30cm ruler ± 0.1 cm, 2x 100mL glass beakers ± 5 mL, electronic balance (± 0.005 g)
- Include a diagram of the experimental setup

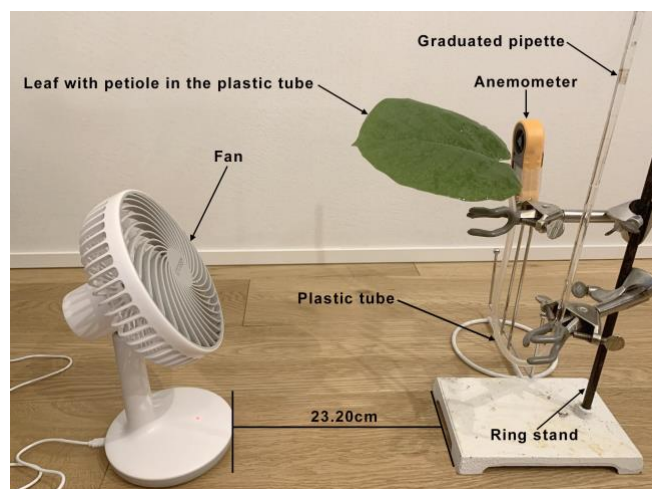


Figure 3 Experimental setup

**A measure of the precision of an instrument is given by its uncertainty. As a good rule of thumb, the uncertainty of an analogue measuring device is 50% of the smallest division. These must be provided*

Method

- Separate your method into sections with subheadings for clarity
- Step by step. Every single step should be included, including how data is collected—the more detailed the better—as the goal is to write a clear enough method that it is easily repeatable
- Include how you will keep controls constant (can reference control table instead of repeating)
- Your method should include how data is collected (both quantitative and qualitative), including diagrams and/or pictures (referenced in steps) - this makes it more personal and can provide evidence

Counting bacterial growth as squares covered:

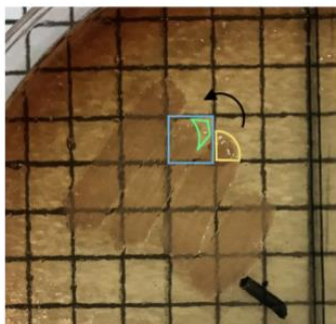


Figure 9. example of how to organize and count number of bacteria filled squares

1. Using a ruler, create a grid with squares of 0.5x0.5cm, making sure that the grid is large enough to cover the petri dish (refer to figure 8)
2. draw the outline of the petri dish and how the quarters will be placed so they are kept constant between dishes
3. Count the squares that the bacteria are covering for each sample, some rounding will be needed. As an example referring to figure 9, when a square is not completely filled (blue), use bacteria in other square (yellow) to fill in the missing surface (green).

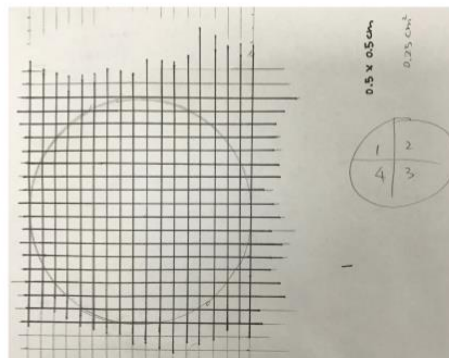


Figure 8. Grid on paper

- In your method, when you mention measuring tools, include how data should be collected and the units and uncertainties of those tools
- If your measurement apparatus requires calibration or pre-trials were conducted, include these
- If your method is based on an established protocol (like preparing agar), cite this. If your method of collecting is an already-known protocol, adapt it for your needs don'

Raw Data Presentation

- Short description on what was collected in order to answer RQ and how it is presented

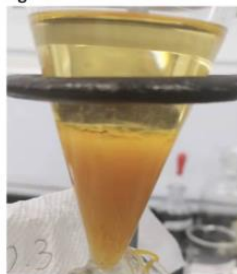
Raw Data, Qualitative

- Observations should be included (perhaps in a table form if it is observational data over time)
- Should be accompanied by pictures (either here or referred to in appendix)

1.75wt%

Solid formation in separatory funnel

Fig. 2.1



A half solid material sedimented in 2/3 of the trials. This material melts with body temperature and is of a golden opaque color. The one trial that formed glycerin (clear) also had a layer of solid forming between the glycerin and crude biodiesel (Fig. 2.1).

Raw Data, Quantitative

- Tables of raw collected data

Table 1 – short but specific description of table (including study species, time period, etc.)

Independent variable (unit ± uncertainty)	Dependent variable (unit ± uncertainty)				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
IV group 1	0.00	2.03	2.22	2.68	2.11

X = anomaly

Independent variable (unit ± uncertainty)	Trials	Dependent variable (unit ± uncertainty)			
		Day 1	Day 2	Day 3	Day 4
IV group 1	1				
	2				
	3				
	4				
	5				

* Tables need to include title, caption, units and uncertainties in headings, and do not span multiple pages

* presented data needs to match the listed uncertainty and all be listed to the same precision. Even

* Raw data should typically not include calculated values (mean, st. dev, etc.)

Processed Data

- Include a short description of what calculations and tests were conducted
- Include description of how uncertainties were determined and calculated → [guide](#)
- Tables of processed data (data that has been calculated), such as mean/average, changes/rates, St.Dev. (Standard Deviation), CV (coefficient of variation), etc
- For each type of calculation, include a formula and a worked example (if you have the space)

Ex:

Percentage Germination Success: The formula used to calculate the concentrations for each trial was taken from a prior study that also examined the impact of pre-emergent herbicides on the germination success of rice. (Khaliq, and Maloob, 2012)

$$\text{Germination Success (\%)} = \frac{\text{No. of seedlings with hypocotyl + coleoptile length that exceeded 2mm}}{\text{Total No. of seedlings tested}}$$

- Ensure decimal points are consistent (mean sig fig same as raw data)

** Data requirements for valid analysis and statistical analyses: IV: min. 5, DV: min. 5 repeats/samples

Independent variable (unit & uncertainty)	Mean Dependent variable (unit)	Standard Deviation	Coefficient of Variation

Statistical Analyses

- Include a short description of what statistical tests were conducted and justify why these were done
- Include null and alternative hypotheses for these tests
- Provide full statistical results (example for ANOVA: SS, df, MS, F, P-value, F-crit)

* **If you need help with statistics, read [my guide](#)**

Ex:

Table 11: One-way ANOVA for FGP of GA3 pretreated seeds at different NaCl concentrations.

If $p\text{-value} < 0.01$, there is a significant difference between FGP at different NaCl concentrations. (Vasavada, 2016)

One-way ANOVA					
Source of Variation	SS	df	MS	F-statistic	P-value
Treatment	198.4000	4	49.6000	9.3000	0.0021
Error	53.3333	10	5.3333		
Total	251.7333	14			

Table 12: Tukey HSD Post-hoc test of the FGPs of GA3 pretreated seeds at different NaCl concentrations.

When $p\text{-value} < \text{significance level, } 0.05$, it can be assumed that the two treatment pairs are significantly different from one another. (Vasavada, 2016)

Treatment pair	Tukey HSD p-value	Tukey HSD inference
0.06 M vs. 0.12M	0.8999947	insignificant
0.06M vs. 0.18M	0.6225458	insignificant
0.06M vs. 0.24M	0.0342434	$p < 0.05$
0.06M vs. 0.30M	0.0115744	$p < 0.05$
0.12M vs. 0.18M	0.2831867	insignificant
0.12M vs. 0.24M	0.0115744	$p < 0.05$
0.12M vs. 0.30M	0.0040854	$p < 0.01$
0.18M vs. 0.24M	0.2831867	insignificant
0.18M vs. 0.30M	0.1020413	insignificant
0.24M vs. 0.30M	0.8999947	insignificant

Tukey HSD:

Table 3: p-values of Tukey HSD test

Wood ash concentration(%)	0	20	40	60	80	100
0		0.8688	0.3512	0.0030	0.9985	0.8582
20			0.9375	0.0411	0.6575	0.2478
40				0.2478	0.1837	0.0411
60					0.0011	0.0002
80						0.9739
100						

*Highlighted values are less than 0.05 (significantly different with 95% confidence level)

*Full calculation is attached in the appendix.

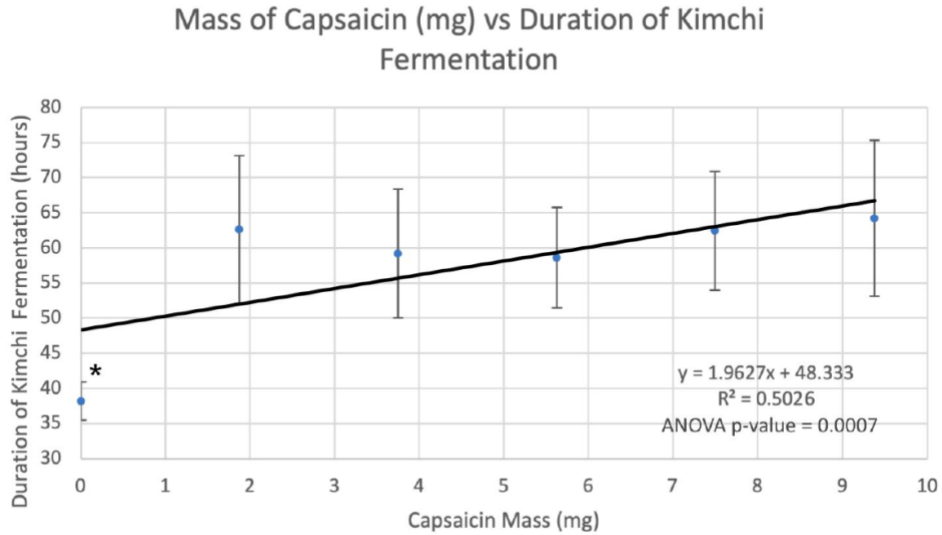
Graphs

- Graphs clearly and effectively represent data – need to be legible and neat and be the correct type; this will depend on whether your data is continuous or discontinuous
 - If continuous vs continuous → scatter plot
 - If continuous vs discontinuous → bar chart
- For a guide on how to use excel to create graphs like a scatter plot, [go here](#) and add error bars, [go here](#)

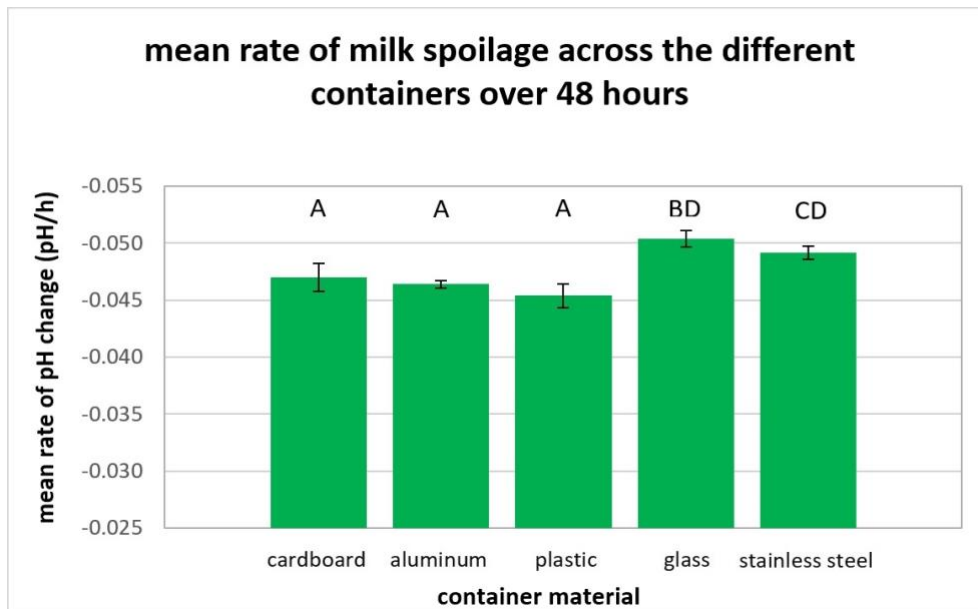
* Graphs need to include title, descriptive caption (including sources of error bars), axis labels (with units ± uncertainty), legend (if applicable), vertical error bars (from StDev), horizontal error bars (from apparatus uncertainty) trendline and r^2 (if scatter plot) and be scaled appropriately (not too small or blurry)

Ex:

Graph 1: Capsaicin mass (mg) vs duration of kimchi fermentation until achievement of optimal pH (error bars were derived from standard deviation values seen in Table 2):



* denotes a group which is significantly different from other groups (Tukey HSD $p < 0.05$ or lower)



Graph 1
 Mean rates of spoilage across the different container groups
 (Error bars calculated from standard deviation - means with different letters are significantly different (Tukey HSD $p < 0.01$) (see Appendix 1 for the full statistical analysis)

Analysis

- Discuss qualitative data. Any trends here or outliers in your observations? Refer to figures/photos
- Interpret the patterns and trends in the data, refer to tables and graphs when reporting numbers/trends. Compare groups and trials/repeats. Be specific.
- If you presented a LOBF and r^2 then interpret these
- Describe the variation in the data (vertical error bars): relative sizes, overlap, values, etc..
- Describe variation in the measurement of data
- Discuss possible anomalies/outliers in data. Did you need to remove data, and if so, does this impact your findings?
- Statistical test results: calculated vs critical value for stats tests, *p value* → do you reject or fail to reject null hypothesis? What do these tests suggest about differences in your IV groups?

Conclusion

- Provide an overall conclusion based on your data and analysis.
- **What scientific explanation are there for your observed results? *Should be much biological theory and references for support.***
- Re-state and answer your RQ.
- Does this support (not prove/disprove) your hypothesis or not?
- Discuss the strength of your conclusion: Do the trends/patterns or apparatus/measurement uncertainty have problems making it difficult to be certain?
- How do your results compare to those of previously conducted investigations/research data?
- What does this mean for your previously-established context?

Evaluation of Method

Strengths:

- Details about your method and how it helped to provide reliable data to answer your research question. Can discuss how your method was novel or unique. Can mention strong data (low St. Dev, low p values leading to reliability in results). Potential applicability of results.

Weaknesses and limitations:

- Be honest here! Discuss the quality, reliability and limitations of the data collected and any possible sources of error, i.e. Was method appropriate/adequate at obtaining a valid conclusion to your RQ:

Factors to consider:

- was there enough range of IV?
- Was there is enough repeats of DV?
- Was enough time provided for data collection?
- Were control variables adequately controlled?
- Was the measurement apparatus adequately precise?

* Note: Errors discussed should typically not include human error and mistakes made. These are avoidable and if they occurred, method should have been repeated.

Suggestions for Improvement:

- For each weakness provided, explain clear, specific improvements/suggestions to how this method could be improved in order to better answer RQ
- Be specific in terms of values/quantities, materials and apparatus you would use
- Suggestions should be reasonable to a high school student context
- Recommended to include this as a table for ease and clarity:

Weaknesses/limitations	Suggestions for Improvement

* While written for social sciences, [this guide](#) can give you more information

Future Directions/Extension

- What should be investigated next: different IV groups (different values/range), different DVs, different conditions? *Future directions are not suggestions to improve the current investigation but what should be explored further based on your findings/context, i.e. next steps*
- Connect the research study to possible real-world applications

Works Cited

- Include all referenced material in a consistent format (I recommend [scientific format](#)) → [generator](#)
- List in alphabetical order
- References should be from various reputable sources (not from the same few over and over)
- Vast majority of references should come from peer-reviewed journals. IB textbook is also ok

Ex:

Robinson, P. K. Enzymes: Principles and biotechnological applications. *Essays in Biochemistry* **59**, 1–41 (2015).

Appendices

- Not necessary, avoid if possible
- Include any supporting material or images that do not need to be in the main body of the report but can be referred to. These should be annotated as well.
- Examples of what could be included:
 - complete raw data (qualitative/quantitative) if you collected A LOT and can't fit it all in the body of your IA
 - full statistical measures and results (main stats results should still be in body)

Reminders:

- Normal margins. Arial. Font 11
- Page length: 6-12 pages. ***DO NOT GO OVER 12 PAGES; examiners will not read past 12 pages***
**Note: Does not include works cited, or appendices (if included)*
- Try to write in third person/passive voice whenever possible - avoid first-person
- Double-check all spelling and grammar throughout the report. If complex scientific, content-specific language is used, ensure you understand its meaning and define it in the report
- Convert your IA to PDF and then check the following:
 - formatting: headings, subheadings, page numbers, margins, tables, captions, symbols, etc.
 - all in-text citations where appropriate
- Double-check your IA with rubric to ensure it meets **all the criteria**

Disclaimer:

I wrote this guide as a DP biology teacher both for my students as well as my colleagues, as the IA rubric and expectations are sometimes unclear. While I studied biology at the graduate level and took an IB PD on the IA, I am not an IA examiner and this guide does not necessarily reflect the views of the IB. Not everything I suggest is required for a successful IA, but I included elements that I felt are important in the writing of a strong science academic paper. I synthesized elements from other teachers, guides, and free online resources.

The official IB Biology subject guide can be found [here](#).

For further information see these other useful IA guides from [eycawat](#), [biology for life](#), [mrGscience](#), [IAcreator](#)