WRITING A GOOD IB CHEMISTRY LAB

PLANNING – (Personal Engagement & Exploration)

This section applies to Aspects 1 and 2 of the IB Rubric.

1. Decide what to investigate

Start with something you are curious about or interested in. Think about:

- Why do I want to study this?
- What do I already know?
- What am I curious about?
- Can I spend a lot of time looking at this topic and maintain my interest?
- Is this topic unique? Creative?

Next thing about your variables!

a) Decide what you want to find out about – this is your *dependent variable*.
b) Brainstorm (and list) all the possible variables that could influence your dependent variable.
c) Choose ONE to be your *independent variable*.
d) All the others will be your *controlled variables*.
e) Think about if you need a control group? Do you need one setup under "normal conditions" that you can compare your results to?

Variables are factors that may affect the outcome of your experiment. They are measurable factors, not pieces of equipment. Do not use the word "Amount". It is not specific enough – terms like mass or volume are better.

Independent variable: This is the variable that you manipulate – you choose the values to investigate.

Dependent variable: This is the variable that changes in response to changes in the independent variable. It is what you are measuring or trying to find out.

Controlled variables: These are other factors that may also affect the dependent variable. They need to be kept constant in order to ensure a fair test.
Uncontrolled variables: Usually climate factors that you try to keep the same for each sample.

Control Group: a set of samples that are not exposed to the independent variable. Used for the purpose of comparing something to "normal" conditions.

2. Write an Aim/Problem/Research Question

a.) Briefly state what you are trying to find out.
b.) Include both the independent and dependent variables.
c.) Specify the scope of your experiment by stating the context of your investigation.
d.) It is unlikely that your experiment will allow you to draw a conclusion that applies to all situations.
e.) Therefore you need to state the conditions under which your experiment is operating e.g. type of reaction, states, location etc.

A good format is "To determine how [the independent variable] affects [the dependent variable] in [the context of your experiment]."

e.g. To determine how the concentration of a named acid affects the reaction rate of a stated reaction.

e.g. To find the effect of different salts on the freezing point of water.

3. Identify the variables

Make sure you have read the information on variables (textbox in Step 1).
Including a variable table in your experimental design might help you organize yourself and your lab.

a) State the independent variable.
a) State the levels of the independent variable that will be tested (see step 5a for more information).
b) State the dependent variable with units, uncertainties & range.
c) State how the dependent variable will be measured (if it can't be measured directly).
d) List the most important controlled variables.
e) Give brief (but specific) explanation of how you will control (keep at a constant value) each variable and why it should be controlled. Including this in the variables section ensures that you have considered each of the controlled variables.
f) If a variable cannot be controlled, state this. Then describe how you will try to minimize any change and/or how you will monitor the variable. See Appendix 1 for uncertainties to consider.

Example for Step 3f.

Controlled variable	Method to control the variable	Reason for controlling variable
Temperature at which reaction occurs	The test tubes in which the reaction occurs will be placed in a water bath set to 40°C for the duration of the reaction.	Temperature affects the rate of reaction. Therefore if temperature is hotter, then the reaction will occur more quickly…

4. List the equipment (apparatus and materials) needed

Make sure that your equipment list includes all of the following:

a) All of the equipment and materials needed for the experiment (after writing you method read through it and check of the items used as you go on your equipment list)
b) Numbers of items (e.g. 2 petri dishes)
c) Volumes and concentrations of any solutions needed (e.g. 300ml of 0.5M hydrochloric acid)
d) Precision (and range if appropriate) of all measuring instruments. How precise do you need to be in your measurements?
e) Sizes of beakers or other items (e.g. 250ml beaker, 10cm length of dialysis tubing)
f) An **annotated** photograph of your setup would be good to include here.
g) A bulleted list is appropriate for this section.

5. Plan and write a method/procedure

Planning a Method

Your plan should allow you to collect "*sufficient relevant data*". The following considerations are important to ensure that you collect enough data and that the data will help to answer your Aim:

a) What values of the independent variable should you test?
   i. *How many* values should you test? Decide how many values will be needed to show any trend or pattern. Plan for an ideal situation – worry about time constraints later. Usually 5.

Number of Values
If you are looking for a correlation, at least **5 different values** are needed (the more the better).

ii. What is an appropriate *range* of values?

b) How will you measure your independent and dependent variables?
    a. Can you measure it directly (raw data) or do you need measure other values (raw data) and use them to calculate values (processed data) for your independent variable?
    b. What measuring instruments will be best to use? Do you know how to use them?
    c. What level of precision is required in your measurements?
    d. What units will you use to record your measurements?

c) How may trials or replicates need to be carried out?
    a. Consider how you are going to process your data
    b. Now go back and double check that you have collected enough of the right types of measurements. Plan for an ideal situation – worry about time constraints later.

d) Will any calibration of equipment need to be carried out to avoid any errors and uncertainties in taking measurements? How will this be done?

Range of Values
You may need to do some research to help you decide. e.g. if testing acidic rain solutions then you would want to test values around 5.6 pH. If you are investigating chemical spills in you might want lower pH values. You might need to run a **test trial** to determine the optimal range.

Number of Trials
All systems, because of their complexity and normal variability, require replicate observations and multiple samples of material. Remember that a **minimum** of 5 values is needed for calculating means and standard deviations. Other statistical tests have other requirements.

6. Write the Procedure

A clear, easy to follow method is necessary to collect useful data. Think about methods you have seen and what information **you** like to have! Someone (who has not done the experiment before) should be able to follow your procedure and obtain similar results.

The following features contribute to writing a good method.

- The method can be written as instructions like a recipe (bullets or numbered list)
- Do not begin with "Gather all of the materials" … it is kind of a given that you will do this!!
- Use numbered steps (rather than paragraphs).
- Use a diagram if possible to show how to set up any equipment. Then you can say "Set up the equipment as shown in the diagram". This would save you writing a lot of words.
- Specify what will be measured (and the units to be used)
- Include details of how you will measure values

DATA COLLECTION AND PROCESSING (Analysis)

This section of your lab is focused on the collection and processing of data.

RAW DATA refers to the values obtained from the measuring instruments exactly as they were shown. Once you do any addition, subtraction, multiplication or division then it becomes **PROCESSED DATA**.

1. Record you RAW data

It makes the communication aspect of your lab easy to evaluate if you keep your raw and processed data separate.

Raw data should include quantitative (always!) and qualitative (usually appropriate) data.

Raw data should be displayed in a table (qualitative data may be recorded under the data table).
In constructing a data table you should consider the following features:

Quantitative data – numerical values obtained from the measuring instruments (e.g. temperature, mass etc) or by other means e.g. counting

Qualitative data – non-numerical observations. Other observations made during your experiment that may have a bearing on the conclusion or help to explain patterns and trends (or the lack of!). Examples include changes in colour, texture, size, bubbling, etc.
Any other observed sources of error should also be recorded.

a) Structure
   a. When possible, the independent variable should come first in your columns followed by the dependent variable.
   b. Show lines around all rows and columns
   c. Make it clear. A good table should be able to be understood out of context (i.e. not embedded in a lab report describing the experiment)

b) Title
   a. Title should be descriptive of the data contained in the table. It should include the key variables as well as any specific conditions of the experiment
   b. Should be **numbered** consecutively throughout the report with a specific identifying **title**.

EXAMPLE
Table 1: The relationship between temperature and water uptake in a leafy shoot of a geranium (*Geranium carolinianum*)

c) Headings
   a. Columns should be clearly annotated with a **heading**, **units** (in heading not body) and **uncertainties**. Headings should indicate what the data is in the column below
   b. Headings are likely to be the name of a variable

d) Units
   a. Units should be included with a heading (not next to each data value in the table)

e) Uncertainties

a. All measurements have uncertainties and you should indicate them in your data tables. Uncertainties should be associated with all raw data and an attempt should always be made to quantify uncertainties. (See Uncertainty Lesson to Review if Needed). You should record uncertainty as plus or minus (±) the associated value.

> **Uncertainties**
> The smallest division on a particular ruler is 1mm. The uncertainty could be recorded as ±1mm or ±0.1cm

b. Only **measurements** obtained with a measuring instrument have uncertainties. e.g. Counts do not have an uncertainty

c. REMEMBER: You measured values should have the same number of decimal places as your uncertainty.

d. Uncertainties should appear with the units in the column heading

f) Precision of data

a. There is no variation in the precision of raw data; pay attention to significant figures.

g) Anomalous results – any results that are particularly different from the others need to be identified and excluded from any processing. You must clearly state this.

Further advice on drawing data tables can be found at:
http://www.saburchill.com/IBbiology/sci_invest/006.html

2. Process your data

- Data processing involves combining and manipulating raw data to determine the value of a physical quantity (adding, subtracting, squaring, dividing, using a formula, etc.), and taking the average of several measurements and transforming the data into a form suitable for the graphical representation.

> **Simply plotting raw data is not considered processing.** If the raw data is already in a form suitable for graphical presentation, it is not considered processing unless a line of best fit/trend line is drawn.

- You must show at least 1 sample calculation for each type of calculation you perform.
- You should include a processed data Table which summarizes all of your processed data (don't forget appropriate headings, units, and uncertainties)

a) Look at Your Aim

ALWAYS CONSIDER YOUR AIM.
The purpose of processing data is to show patterns in the data that help you draw a conclusion that answers your Aim.

b) Choose Your Processing Technique

You will be assessed on your ability to choose appropriate processing techniques (types of calculations) and to carry out those calculations correctly.

Some appropriate options for data processing in chemistry are:

i. *Change in quantities* (initial → final)
- This is a very basic processing technique and should be used in combination with other methods.

Change in quantities
$$\Delta = final - initial$$

ii. *Percentage change in quantities.*
- This also allows you to compare quantities that have different initial and final quantities
- This often more appropriate than change in quantity as it helps to eliminate some of the error.
- For example, since it is almost impossible to obtain slices of potato that are the same dimensions, same consistency throughout, and the same mass to the degree of precision that your instruments allow, it is more appropriate to do a percentage change in quantity rather than simple change in quantity calculations.

Percentage change

$$\%\Delta = \frac{Final - Initial}{Initial} \times 100$$

iii. *Rate*
- Rate is a measure of how quickly a variable changes

$$Rate = \frac{Final - Initial}{Time}$$

iv. *Mean and Standard Deviation*
- Whenever you have multiple trials in an experiment, it is good practice to calculate the mean and standard deviation.
- Using the mean as opposed to individual values helps to minimize the error in your experiment.
- Standard deviation also helps to indicate the spread of your values around the mean. A smaller standard deviation indicates that the values are clustered closely around the mean (and therefore possibly more reliable); a larger standard deviation indicates a wider spread (values are possibly less reliable).

$$mean = \frac{\sum values}{\#\ of\ values}$$

See this link for how to calculate standard deviation: http://www.mathsisfun.com/data/standard-deviation.html

v. Percentage error
- This is used when comparing your actual measurements to a theoretical measurement. Percentage error describes the accuracy of measurements.

  You should always use percentage calculations as opposed to the numerical difference. This is because 10 cm error means nothing if you are measuring the distance between Shanghai and Beijing, but it is a huge error if you are measuring the length of a piece of paper.

$$\%\ error = \frac{Theoretical\ Value - Actual\ Value}{Theoretical\ Value} \times 100$$

vi. Percentage deviation
- A measure of precision when a theoretical value is not known. This informs how reproducible your experiment is.

$$\%\ deviation = \frac{Average\ Deviation}{Mean} x100$$

c) Carry out your Calculations
Make sure you go back and double-check your calculations.
See section 3a to make sure that you have presented you work correctly

d) Treatment of Uncertainties
i) The uncertainties associated with the raw data should be taken into account. (See propagation of error video lesson)
Mean and standard deviation are acceptable ways of showing this in graphs with error bars. The mean should be the plotted point or height of the bar. For each point an error bar can be drawn that extends above the point/bar 1 SD and below the point/bar 1 SD. The size of the error bar is also an indication of the reliability of you data (and therefore any conclusion you draw from it)
ii) The treatment of uncertainties in graphical analysis (scatter plots) requires the construction of appropriate best-fit lines.

Further information on processing techniques (when and how to use them) can be found at:

- *http://www.saburchill.com/IBbiology/stats/stats_hp.html*
- *http://moodle.wab.edu/mod/resource/view.php?id=3273*

3. Present your processed data (GRAPHING)

You are expected to decide upon a suitable presentation format without teacher assistance. Your ability to show how you processed the data, choose the correct presentation method and construct graphs
Important things to consider:-

a) Present data so that stages to final results can be followed
This will often mean showing your working for each **type** of calculation done (not for every single calculation done!). Each worked example should include the following:
i) Heading describing the calculation
ii) Formula
iii) Identification of which set of data is being used in that example
iv) Fully worked example
v) If Excel or a graphing calculator was used to generate values (i.e. you didn't have to plug numbers into an equation) it is OK to simply state this. In the case of Excel you should state the formula used.

b) Significant Figures
i) Inclusion of metric/SI units is expected for final derived quantities, which should be expressed to the correct number of significant figures. Your processed data should not have more significant figures (or decimal places) that the raw data you collected
ii) All processed data should be to the same number of significant figures
iii) Uncertainties should be propagated (see video lesson)

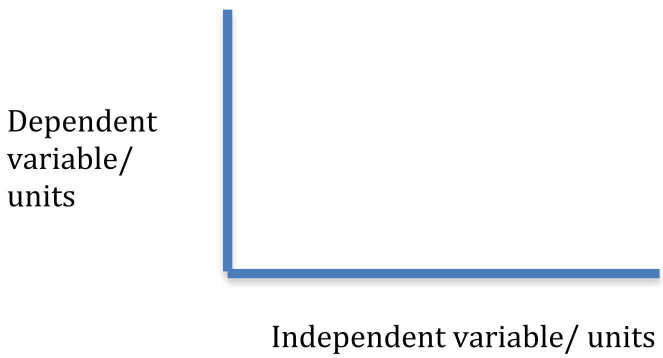
c) <u>Presentation formats</u>

A few general options are listed below; however, understand that you are not limited to these options as there are many processing options specific to certain labs such as population pyramids, and logarithmic graphs:

i. Spreadsheets and tables showing data calculations such as mean, SD, percentage change etc.
ii. Line graphs and scatter-plots showing continuous data points (e.g. time, GDP, age, distance, height etc.) with line of best fit
iii. Bar graphs showing discrete data (categories) e.g. species, sex, ethnicity
iv. Pie charts showing percentages out of 100%

<u>Graphs</u>

viii. Think about why you are drawing your graph …. It should be a visual representation of the data that allows you to answer the Aim. Therefore it should look like



ix. Graphs can be drawn by hand or using graphing software such as Excel (as long as you have had to make the decisions on the format, axes, scale etc.). However, an inability to manipulate the program to show the necessary elements is not an excuse for failing to include them!
x. Graphs must have the following:
   - **Title.** The same expectations apply as for table (see section on Recording Raw Data). Graphs will be labelled as figures. Figures should be numbered for reference and be placed below the figure it references.
   - **Appropriate scales;** if you are measuring temperatures between 30 and 40 degrees, your graph should not begin and end at 0 and 100 respectively. Your units must be appropriate as well. If you are measuring in mm, you shouldn't have meters marked on your graph. Think of a graph like a microscope; you want to see as much detail as possible.
   - **Labelled axes with units & uncertainties**; axes should be labelled similarly to your table headings.
   - **Accurately plotted** data points should be clearly shown
   - A suitable best-fit line, trend line or curve is drawn (for a line graph or scatter plot) DO NOT CONNECT THE DOTS

Further information on graphing can be found at:
http://www.saburchill.com/IBbiology/graphs/001.html

EVALUATION AND CONCLUSION

1. Discuss, review and analyse your results

a) Describe what your results show in the context of you topic of investigation
b) Identify any trends or patterns in your results
c) Compare these to literature, scientific understanding or models or class discussion. If there are differences, identify them and suggest possible reasons
d) Identify any anomalous results and justify their exclusion from processing
e) All literature used to write you lab report should be fully referenced by using MLA formatting to produce:
    a. Bibliography- Help on how to produce a bibliography can be found at http://owl.english.purdue.edu/owl/resource/747/07/
    b. In-text referencing- advice on the correct format can be found at http://owl.english.purdue.edu/owl/resource/747/02/

2. Discuss strengths <u>and</u> weaknesses in your investigation

Evaluate your procedure and the impact on the results. This is where you comment on the design, method of the investigation, and the quality of the data. A good format for the Evaluation is shown to the right. →

Good format for Evaluation

Strength/Weakness	Significance	Improvement

Your Evaluation should include:

a) List specific strengths in the design and carrying out of the procedure. You could look at
    i. procedures,
    ii. limitations of equipment,
    iii. use of equipment,
    iv. management of time,
    v. investigation timing,
    vi. data quality (accuracy and precision) and relevance of data.

b) List specific weaknesses in the design and carrying of out the procedure. Consider:
    i. procedures,
    ii. limitations of equipment,
    iii. use of equipment,
    iv. management of time,
    v. investigation timing,
    vi. data quality (accuracy and precision) and relevance of data.
    vii. See Appendix 1 for a discussion of errors

c) For each strength or weakness discuss its significance i.e. it's effect on your results e.g. values too high/low, data values less reliable (large uncertainty/error/S.D. would indicate this), measurements less accurate or precise, trend/pattern incorrect or unclear etc

Acceptable Example:
"Because the simple calorimeter we used was made from a tin can, some heat was lost to the surroundings—metals conduct heat well. Therefore, the value we obtained for the heat gained by the water in the calorimeter was lower than it should have been. The heat lost from the tin can would not have been a lot in the time taken for the experiment so this probably did not have a significant impact on the results"
Unacceptable Examples:
"The test tubes weren't clean." → careless or poor performance does not make for a valid weakness
"Human error." → a specific description of the type of human error would be required

Describe improvements for each identified weakness

For each improvement ensure that:

a) Modifications are specific (numerical if possible). "Next time we should work more carefully" is not acceptable.
b) Modifications are realistic – they can be achieved within the constraints of the timetable, school setting and budget.
c) Improvements are not overly simplistic or superficial – you need to demonstrate that you are a student at a Diploma level!

Accuracy = how close a measurement is to the correct value

Precision = exactness of a measurement as represented by the number of decimal places to which it is expressed

Reliability = consistency in measurements (i.e. if measurements taken over consecutive trials are all very similar then there is consistency and they are said t be reliable). This can be shown by the standard deviation.

Write a Conclusion

This section should be one or more paragraphs in which you draw conclusions from your results, and reflect on whether or not they are reliable/trustworthy.

To achieve at the highest level for this aspect you should make sure that:

a) Conclusions are truthful and **based on the data**. Don't try and twist your results to fit a hypothesis or expected outcome.
b) The conclusion is clearly related to the Aim.

Bad example
The results show that the concentration of sugar affects the rate of respiration. As the sugar concentration increased so did the rate of respiration.

GOOD example
We can conclude that there is a positive, linear relationship between the concentration of sugar and the rate of respiration. The correlation coefficient of 0.9 indicates that it is a strong relationship.

c) The conclusion provides a **thorough description** of any trends or patterns