**How to do a Deadly EEI in Chemistry**

**- by Dr Richard Walding**

BAppSc, MSc, MPhil, PhD, FAIP, FRACI, CChem,

Research Fellow, School of Science, Griffith University, Australia

Senior Chemistry and Chemistry teacher - Moreton Bay College, Brisbane

Web: seniorchem.com

**Students: These are some hints about the requirements of a high quality Extended Experimental Investigation for the Queensland Senior Chemistry Syllabus. Guidelines given to you by your teacher should take precedence if there is any doubt. They are addressing a Year 12 EEI but will still guide you for Year 11 (or even Year 10). They refer to a hypothesis-testing EEI. [Revised 23 May 2017].**

**What’s the purpose of an EEI?**

You’ll do an EEI to research a question you have about some Chemistry-related phenomena you have come across. In the process you gain a better understanding of the concepts. It does not matter that your experiment has been done a thousand times before or that your teacher already knows the results. What matters is that you don't know exactly what results you’ll get and that you can work independently to find a verifiable answer and discuss the sources of error.

**How do I find a research focus (topic) for my EEI?**

If you are in Year 11, you are most likely to be given an EEI topic by your teacher or are told to choose from a list of maybe half-a-dozen. This helps your teacher concentrate on experimental design, measurement and management skills. In Year 12 however, you are most likely to be given a much more free choice of the topic either within a specific context you may be currently studying, or outside of this. Wise choice of a topic can make or break your EEI. There are several ways to decide:

1. As you progress through your course of study identify concepts/ideas/applications that might be useful as a research focus for an EEI. That is, you should keep in mind some investigation you liked or wanted to know more about.
2. You could select from a list of ideas. Have a look at my website seniorchem.com/eei.html.
3. It might be possible to introduce a degree of complexity into a simple investigation that you have encountered in class time. If you can modify, refine, extend or redirect that experiment you may have a great EEI. For example, you may have measured the refractive index of water and then turn this into an EEI by measuring the RI of salt water at different concentrations or temperatures.
4. Lastly, you could have a ‘brainstorming session’. Get together with a group of other students and think up as many ideas as you can. Think creatively. Don’t comment on each of the ideas that come up. Do not criticise the ideas of others. Some ideas may seem silly or impractical but they can often act as a stimulus and trigger other ideas. The more ideas that are generated, the more likely it is that some of the ideas will prove useful. You might hear “let’s do something with rockets or bows and arrows” so there’s a good start. One member of the group needs to write down the ideas as they are generated. All students need to be involved in listening and thinking. When you have finished brainstorming take a look at the list that has been generated. Select from the list just four or five ideas which you think you might be interested in and able to investigate. As a group try to identify how you would carry out an investigation into these topics.

**How do I decide on a Research Question?**

Once you have decided the research topic you need to formulate a Research Question. It is often a broad question and identifies a query about the 'world out there'. For example, you may ask: *What effect will pH have on stability of ascorbic acid in solution under various environmental conditions?* It must be a question so it should start with: ***How*** or ***What*** (forget about *who*, *when*, *where* and *why*; this is Chemistry not History or Geography).

This is where many students first get into trouble; that is, proposing a research topic without formulating a good Research Question to guide their investigation. For example (this is what not to do): say your research topic is telescopes (which is fine) but your Research Question is *How to make and test a Daniell Cell.* A research question of this nature will limit your ability to demonstrate very high levels of achievement. If you do something like this you are doomed from the start as it is not specific enough. You need to establish a research topic that will allow you to show higher order thinking.

The other things students do is to propose Research Questions that are little more than laboratory analysis, e.g. *“which soft drinks have the lowest pH”* This will not lead to a good EEI; it is just laboratory analysis without any design and critical thinking. If it “*how does carbonation affect the pH of soft drinks”*, you would be a bit better off.

**What’s the difference in wording between an Aim and a Research Question?**

You will need to develop a properly worded “Aim” for your investigation but leave the exact wording until later. The Aim is a refinement of the broad Research Question; it narrows and describes the parameters actually used within the experiment. It should be in the form of an explicit statement (beginning with the word “To”) relating to your variables, eg: “To investigate the effect of (independent variable) on (dependent variable) when (controlled variables) are kept constant”. Here’s an example: : “To investigate the effect of pH on the stability of ascorbic acid in a solution when concentration, temperature and exposure to light are kept constant”. This aim allows us to set the boundaries within which the investigation will proceed. It is critically important as it makes sure your investigation will not be too big or too small.

**Do I need a hypothesis?**

Not all scientific research involves testing hypotheses but for a Senior Chemistry EEI, most schools will require it. There is no mention in the syllabus of necessarily proposing a hypothesis but most teachers make it a requirement of the task. These guidelines are written with that in mind. The formulation of a hypothesis forces you to state clearly what you intend to measure and change. This is crucial as a lead in to your experimental design.

**How do I write a hypothesis?**

In real experiments, real hypotheses should be written before the actual experiment begins. A hypothesis should not be confused with a theory. Theories are general explanations based on a large amount of data. For example, Henry's Law (about the solubility of a gas being directly proportional to the pressure applied to the gas) applies to all matter and is confirmed by a wide range of observations. However, there are many things about gas solubility that are not fully understood (as climate change scientists are finding) so chemists are forever proposing and testing hypotheses about it. Usually, a hypothesis is based on some previous observation. For example: noticing that the pressure of gas in a soft drink bottle is higher when it is hot. Are these two events connected and, if so, in what way?

**Terminology reminder:** Formalized hypotheses contain two variables. One is “independent” or sometimes called “manipulated”; and the other is “dependent”. The independent variable is the one you, the “student chemist”, manipulates (changes) and the dependent variable is the one that you observe and/or measure the results of. Factors that you control are called the “controlled” variables. In the example above, the manipulated variable is [H+], the dependent variable is ascorbic acid concentration, and the controlled variables are the concentration, temperature, light intensity and duration of the testing.

**Writing a hypothesis** is the tricky part and probably the most important part of an EEI. All EEIs have a Research Question followed by a more specific Aim, generally followed by a ‘testable’ hypothesis. This hypothesis gives a tentative explanation for an observation, phenomenon, scientific problem (posed in the Research Question) that can be **tested** by investigation. Most of the time a hypothesis begins like this: “That as \_\_\_\_(this is done) \_\_\_\_\_, then \_\_\_\_\_(this will happen) ”.

For example: It was hypothesised that the stability of ascorbic acid in solution will increase with [H+] in the form of Cascorbic acid is proportional to [H+].

OR

It was hypothesised that the relationship between the concentration of ascorbic acid in solution after a measured time and the [H+] of the solution is proportional where the initial Cascorbic acid is 40.0 mg/L, the temperature is 25°C and the solutions are kept in darkness for one week.

**It was hypothesized that…**

**if …(the independent variable is changed in this way) …,**

**then …(the dependent variable will respond in this way )…**

**when …(the controlled variables are kept this way).**

For all hypotheses you must decide on the three types of variables and state them in your report.

**How can I state a hypothesis if I don’t know what will happen when I make a change?**

The ultimate value of a formalized hypothesis is it forces you to think about what results you should look for in an experiment and should inform (be the basis for) the experimental design. If you are not sure what will happen to the dependent variable when you make the changes to the independent variable then you could use the word “may”. For example: if the acidity of seawater is changed then the amount of corrosion may change.. This is still a hypothesis because it uses the tentative word “may” but it lacks complexity and thus limits your capacity to demonstrate the higher order thinking skills required to access the criteria at the higher achievement levels. You’d be better off reading up on the chemistry theory and making the statement definite: if the acidity of seawater is increased then the amount of corrosion will increase. So what if your hypothesis is not confirmed? So long as you can base it on well-argued chemistry theory then it won’t matter. Nobel laureate and Brisbane-based scientist Peter Doherty said that he often writes his hypotheses after the experiments are finished to make the report easier to understand.

**How many variables should I investigate?**

So that you have sufficient time for the experiment you may chose to investigate only one dependent and one independent variable. However, depending on the complexity of the task, you may find it necessary to investigate more than one variable so as to allow a depth of analysis. To ensure that the task allows for a sufficient degree of complexity it may be necessary to include two independent variables. This will depend upon the nature of the research focus. For the resistance experiment a second independent variable could be the diameter of the wire. Or you could change the type of wire - compare nichrome with platinum etc and see if their temperature/resistance curves are similar. The concern with selecting **too many** dependent variables is that the experimental design will become increasingly more complex and you risk taking on more than can be achieved in the time available. So be warned - just choose one independent and one dependent variable and if you want to turn your EEI into a monster then discuss you planning with your teacher first.

**What makes a good Hypothesis?**

Your hypothesis should be something that you can actually test - what's called a **testable** hypothesis. In other words, you need to be able to measure both “what you do” (change the temperature) and “what will happen” (resistance will change). It also forms the basis of your later analysis of the data.

The requirements for a good hypothesis includes the magnificent seven:

**1. It has to define the variables.** That is, state the dependent and independent variables (and mention the controlled variables).

**2. It has to link the variables.** That is, it must make a statement about a change in the independent variable (IV) and its effect on the dependent variable (DV) in the form: if…then….

**3. It has to be testable.** That is, you can actually carry out the investigation and get some results which will clearly either support or refute (contradict) the hypothesis. Some examples are:

 • if the oxygen concentration (IV) is increased then the corrosion of iron (DV) will also increase;

 • if the temperature of a Daniell Cell (IV) is increased then its EMF (DV) will decrease.

 **Note:** If your investigation is more trial and error then you may choose a more general statement (a “prediction” rather than a formalized hypothesis):

• if the mass of water, pressure and nozzle diameter of a water rocket are changed then the maximum height will change;

• if the shape of the tail fetches of an arrow are changed then the arrow’s range will change.

 A hypothesis that would not be testable is: *as the Earth warms then the amount of carbon dioxide in the oceans decreases.*

**4. It has to be significant.** That is, it has to be worth knowing and not too trivial. An important question to ask is: are my results of practical or scientific importance (eg design of insulation in clothing, sporting gear, electronic equipment, adding to scientific knowledge etc). A hypothesis is also not significant if it is just about proving what is already well (eg Dalton’s Law of Partial Pressures) or something that is too dumb: eg that if water is heated then its temperature rises. Don’t just state the bleeding obvious!!

**5. It has to be valid.** That is, it has to be based on some Chemistry concept, idea, law or principle. The hypotheses given in Point 3 above are all valid. Hypotheses that are not valid would include:

 • that chocolate ice-cream tastes better than vanilla (this is Chemistry not Playschool);

 • that the acidity of soft drink varies with the time of day (it may be testable but what are the Chemistry principles?).

**6. It’s testing has to be manageable.** That is, it has to be able to be conducted over a period of a few weeks. It would be of no use to begin an experiment on the annual variation of geomagnetism and expect useful results over two weeks. As well, you should consider if you can manage with the usual laboratory or home equipment. It is no good expecting the school to order equipment or chemicals as they may take weeks to arrive; and you should also find out if your school will be paying for it. You could assume that technical advice about using equipment (e.g. pH meters, data loggers, video capture cameras, computer interfaces, voltmeters etc will be given by your teacher or the laboratory technicians – but this may not always be the case.

**7. It’s testing has to be safe.** You shouldn’t formulate an EEI that requires adult supervision (plating out bacteria, using radioactive samples, scuba diving, heat of combustion of petrol) when no supervision will be available or the hazards cannot be minimized or controlled. You will be expected to complete a Risk Assessment form anyway so it might be best to quickly decide if your project is safe from the outset and not waste time.

**Do I need a logbook or journal? If so, what do I keep in it; is it assessed?**

A logbook or journal is notebook in which you can record your research question, aim, hypothesis, the list of equipment that you need, your method, all results and all other work. Practicing scientists use this technique all the time. Essentially, it is a no-frills, on-the-spot recording of the essentials of your work in one place and can be later used for your report writing. If you make changes to the method or if you have problems which need to be overcome, this information should be recorded. You might like to include diagrams of the equipment that you used, especially if it is a very special arrangement of unusual equipment. If you have difficulty with drawing, a photograph could be useful. It need only be intelligible to you but it may be used to verify the authenticity of your work. A note from a professional scientist can be found at seniorChemistry.com/notebook.pdf. Your teacher may choose to have you record your notes in the form of a blog (which then includes a date stamp).

Start writing in your journal from the start. Make a note of the date of each entry. Glue in sheets you have run off or have photocopied. Your journal may not be directly assessable but it can be used to verify that you have engaged in the research process. But teachers and review panels may choose to refer to your journal as a way of authenticating your work. You may prefer to keep your journal electronically as you go, so obviously it is okay for these to be typed. You may have to submit a printed copy with your report.

**How much background research do I need to do?**

You may be given class time to develop your research question, write a hypothesis and find supporting information.

There are two areas that you need to collect information for. Both require reference to Chemistry principles, facts and concepts. They are your:

(a) **Research focus (topic):** what is the background theory (this is not required in most schools).

(b) **Hypothesis:** how can it be justified

You may spend some time on (a) before you can move on to (b).

References: Keep detailed record of references as you collect information, not later. Have you used a variety of sources (not just *Wikipedia*)? How reliable are the sources?

**(a) What is needed for the background theory for my research topic?**

As this stage you should be locating, identifying and collecting relevant data and information.

You will need to develop an understanding of the principles of your chosen topic. By use of the library, internet, textbooks or other source of information (parent, expert, others in your group) you should clarify some or all of the following:

1. What do we know already about this issue (up-to-date facts about the Chemistry principles behind my research question).
2. Were there earlier ideas that have been overturned (perhaps a little bit about the history of the idea).
3. How is it measured (what measurement techniques might I use, and what others would be good but I have no access to them).

The information must continually refer to your research question. Irrelevant content will be easily noticed and it will detract from your work. NOTE: In Queensland, since 2010, the need for a detailed Introduction has diminished. A paragraph or two that gives the reader an idea about what the EEI is attempting is sufficient. Chemistry, facts, theories and principles can be referred to in the Hypothesis Justification and Discussion.

**(b) What is needed for justification of my hypothesis?**

The second theoretical part of an EEI is about **justifying your hypothesis**, again by referring to Chemistry principles. You will be given hints about writing your report later but you must be aware of what you are looking for otherwise you will waste time just scrolling through pages of irrelevant Chemistry information. The key phrase is **justifying your hypothesis**. You have to show the reader that your hypothesis makes sense and is backed up by Chemistry theory. So at this stage of the research process just **gather** information specifically related to your hypothesis.

1**. Facts:** Gather facts and information: they must be relevant to the hypothesis. Don’t just copy chunks of information unless it is relevant or helps you understand the concepts. This probably will include formulae so keep a note of the quantities (eg pH, temperature), symbols (E°, T) and units (concentration, mol L-1; pressure, kPa). You can select the useful information later.

**2. Linking:** Gather information to link the information together so that it tentatively supports your hypothesis. Eg: the nature of activation energy and how temperature affects reaction rate? The key word is **linking**: don’t try to pretend you have linked the ideas. It will be so obvious to the teacher if you haven’t.

**3. Measurement:** Gather information about how the variables are to be measured. Ask: what instrument is used, how does it work, how is it connected up, and what are the techniques for using it and reading it accurately? It is important at this stage that you take note of the uncertainties involved in the measuring process. Later, you will take all of these measurement uncertainties into account and calculate both your absolute and residual errors involved in your investigation and make some sensible analysis of your results and measurements in the light of these errors. For instance, it is commonly assumed that any reading can be made to within a half-scale division of the measuring instrument. For a ruler graduated in millimetres this would mean an uncertainty of ± 0.5 mm and you would record this in your journal.

**How do I design my investigation?**

In your journal:

**•** Define your variables. What is your:

 **•** independent (manipulated) variable/s (what you will change)

 **•** dependent variable/s (the result)

 **•** controlled variables (what you will keep constant).

**•** Plan your approach:

 **•** Draw a diagram of your setup;

 **•** Make some rough estimates of the quantities you will be measuring (volume, time, temperature, mass, length, voltage, angle…);

 **•** Decide on how many trials to do. Three trials (i.e. three different values for the independent variable) may give enough data if the relationship is linear, but be warned, errors in measurement could cause an illusion of a linear relationship where none really exists. Five trials (i.e. with different values for the IV each time) are far better and should be considered a minimum; 7-9 data points would be better still if you really want a justifiable equation for your proposed relationships. For each trial you would be wise to collect data in duplicate (2), or even better, in triplicate (3). This is also useful for calculating your residual errors and helping with justification.

 **•** State the method briefly; propose a data table with columns labelled. Allow space for triplicate trials and an average if that’s what you are doing.

**•** Decide what equipment will be necessary.

* Ensure the design of the experiment is both effective (will test the hypothesis) and efficient (not a lot of wasted time). For example, you don’t want to have to reassemble the equipment for each trial.
* Ensure that you assess the risk and make a selection or adaptation of equipment with safety in mind.
* Ensure you use appropriate technology to gather, record and process the data.

**What happens if there are concerns about the viability of my EEI proposal?**

By this stage you will probably have reached the first Checkpoint (or Monitoring) and will have to complete some forms for your teacher. If you can state your Research Question, Hypothesis and overview of the plan you should get a quick go-ahead. Often various forms are to be submitted to your teacher for review and approval. They may include:

**• Research Proposal Sheet**.

**• Risk Assessment Sheet**

**• Materials Requisition Sheet** (be as specific as you can to speed things up).

**How will I know what size to make the variables?**

EITHER – Use formulae and calculations to establish a range of workable values;

OR - Do some preliminary trials (sometimes called a Pilot Study) – and you should record all observations, measurements, problems, changes in approach and modifications to your initial plans and procedure in your journal. If it doesn’t work and looks like it will never work then talk to your teacher and perhaps abandon it quickly.

**How long should I spend on the laboratory work itself?**

You would be wise to restrict the time spent on the experimental work to between one-quarter and one-half of the total time. You should record all observations, measurements, problems in your journal. Once you start analysing your data you’ll probably find some anomalies that you’ll want to go back and check. Be prepared for this. You may think you have plenty of time but students always find they have to rush the report writing to meet the deadline.

**What is expected in a good EEI Report?**

An EEI Report is all about communicating ideas clearly and concisely. Remember you are not graded on the number of pages in your report. The syllabus makes it quite clear: for an “A” there should be *discriminating selection, use and presentation of scientific data and ideas to make meaning accessible to intended audiences*. Your *intended* audience may be specified in the criteria sheet but if it isn’t assume that it is one of your peers (Senior Chemistry students). Your goal should be for the information that you present to flow effortlessly from the page into the reader's mind without the reader's head ever snapping back in shock or drooping forwards as they doze. It takes a lot of practice to become a good writer, and you aren't going to master the art overnight. But here are a few tips for you to focus on that will help you find your voice and keep your audience.

Firstly, always, always, always write in clear, declarative sentences. *Declarative* means that the sentence simply states an idea or piece of information; it is not a command, request or question. This article you are reading has short and clear sentences. The topic sentence grabs your attention, just as any good topic sentence should. Each idea thereafter flows naturally into the next. This is how you should strive to write every paragraph of your EEI Report. And for goodness sake, break up your text into paragraphs.

Whatever you do, don't overwork your sentences! Each sentence should contain just one complete idea. Too many run-on sentences read like the writer let him/herself be swept away in their own stream of consciousness. Was the writer too lazy to think about what he or she was trying to say?

**Should I use passive voice?**

Virtually every science paper is written in passive voice. However, prize-winning writers who know how to write hate passive voice, they struggle against passive voice at every opportunity. Why? Because passive voice seems boring as it makes the object of an action (the brass weights, the inclined plane) the subject of the sentence, rather than relating that a person (I, we) carried out the action.

Active voice using personal pronouns is not recommended:

Examples are: *“We adjusted the temperature to...”. or “We took the data...”.* But the Passive voice is recommended for scientific reports.

Examples are: *“This temperature was adjusted to ...” or “The data was/were taken...”*

It is customary to use passive voice in scientific work (particularly in the ‘method’ section) but you should check the task criteria sheet because your teacher might want you to try something different by presenting your EEI in a different format. Many prestigious scientific journals now accept active voice. Remember, the key point is *to make meaning accessible.*

**How technical should I get?**

Scientists often use technical terms when communicating with each other in the same field but you must judge which technical terms need explaining. You should reserve technical jargon that is not familiar to fellow students only for those instances when jargon is actually appropriate. Students sometimes believe they can hide their ignorance or poor technique behind a smoke-screen of obtuse language. Being difficult to understand doesn't make your writing sound more knowledgeable. It does more harm than good. Pretend you are explaining it to a classmate who has been away. *Frequency and molar heat of combustion are okay, but anisotropy, isochoric and nanoarchitectonic need explaining.*

In summary:

• short, clear, declarative sentences; consistent tense

• familiar language

• no unnecessary words

• limit technical jargon and explain unfamiliar terms

• grammar and spelling are free of error\*

• technical terms have been used appropriately.

\*Note – you must proof-read your report. Too many students simply trust the spell and grammar check on MSWord to do the editing work for them and miss some critical literacy issues.

**What are the main parts of the report?**

You will need to write an individual report but you can work on the design and data collection in collaboration with others in your group although it must be noted that design of investigation and management of the investigation are individually assessed criteria. Report writing involves collating all you’ve done into a report of your investigation. It should be like a story that unfolds as you go, making the reader wonder how well the hypothesis was confirmed. But it should also be persuasive, in the sense that you are persuading the reader that you were honest and accurate, and manipulated the variables carefully and it is undeniable that your conclusion follows logically. Other people’s ideas, statements, diagrams, photos and so on should be correctly referenced. Your work must not contain plagiarised material – this also includes copying large sections of the report from other members in your group. Consult one of the ‘what is plagiarism’ websites if you don’t have it on your school’s intranet.

**How much feedback should I expect from my draft report?**

The amount and format of feedback provided to students is usually determined at the school level but in general, you are more likely to get more feedback in Year 11 than in Year 12. Remember that ongoing discussion with your teacher as the EEI progresses is a form of feedback and probably more valuable, in many respects, that feedback on your draft report. You may be required to submit a draft of your report to your teacher for comment (usually once only) but remember that the amount and type of feedback given will be in general rather than specific terms to ensure that the final report reflects your understanding rather than your teacher’s understanding.

**MAIN PARTS OF A REPORT**

**Please see the checklist at the end which gives you a good summary of what is needed for a Deadly EEI. You could use this for Chemistry, Physics or Biology. I use if for my Junior Science classes as well.**

The words of the great scientist Schrödinger are worth quoting here: “if you cannot – in the long run – tell everyone what you have been doing, your doing has been worthless”. This is just as true for EEIs. When writing an EEI report your evidence and arguments should be provided in a very logical order that makes it easy and interesting to follow your train of thought. The headings given below are typical of an EEI report and will help you achieve this logical flow. Note: references citing “How to Write” refer to the book “How to Write What You Want to Say” (Boolarong Press) by Patricia Hipwell. The book describes various language functions used in school essays and gives a variety of useful sentence starters.

Note: [Text in square brackets] contains extracts from the A-standard descriptors from 2016 Queensland Senior Chemistry syllabus (QCAA).

**Title Page:**  subject, assessment task type, title, your name, date, teacher’s name. You may have to make a statement that this is your own work, and it may have to be countersigned by your parents. The task sheet will tell you this.

**Table of Contents:** include the page numbers for the beginning of each section.

**Abstract (or Executive Summary) – not all schools require this.**

**Note: write this after you have written the rest of your report.** An abstract is a paragraph, that if read by itself, summarises the project in the least possible words (usually 100 – 200). It should include the aim, principles/techniques employed and a very brief statement of your results and conclusions. The criteria used will be: *The abstract is a clear, concise, accurate representation of the project, linking the main ideas together well without added interpretation or criticism, misunderstandings or unnecessary details.*

1. Begin with a topic sentence that is the major thesis (the Aim).

2. Purpose: state the research question and hypotheses

3. Method: the design

4. Results: concisely

5. Conclusions: implications of results. Can be recommendations, evaluations, applications, suggestions, new relationships, and hypotheses accepted or rejected.

6. Other information incidental findings to the main purpose of the document but must not distract attention from main theme.

• Write one paragraph.

• Write in complete sentences.

• Use transition words to make the sentences flow (besides, furthermore, in addition, for example, for instance, in particular, finally, consequently, hence, although, however, in comparison, subsequently).

• No equations or images and no references.

# What Are The Criteria For Judging A Good Abstract?

The usual criteria by which the quality of an abstract is judged include: exhaustivity, accuracy, readability and coherence.

***Exhaustivity***deals with how extensively the abstract represents the original document in terms of the ideas, conclusions and so on in the original and yet maintains its brevity. Ask yourself the questions: Is there enough important information included in the abstract; and are unnecessary details included? Are the major “points” of the document brought out in the abstract?

***Accuracy***refers to the extent to which the abstract correctly represents the original text. Ask the question: could there be any misunderstandings in reading the abstract?

***Readability***is how clearly, concisely, and precisely you have written the abstract. Ask the questions: How well is it worded? Are the points described accurately, succinctly, and unambiguously**?”**

***Cohesion/coherence*** is focused on how well the ideas presented in the abstract are linked together. Ask the question: does it read well?

**1. The Introduction**

**Overview (probably optional, check your task sheet)**. In a few sentences you can give a short overview of your EEI.

**Theory Review (probably optional, check your task sheet):** In a few paragraphs, you should tell a story that generates interest in the reader for the field of your research and link to the practical investigation to follow. It will draw on your library or internet research and will be referenced. You should write about Chemistry concepts, theories and principles that directly relate to your project and contain no irrelevant or unnecessary details. In other words – don’t waffle on; every irrelevant sentence is a step backwards. Your aim is to show understanding of the Chemistry involved and how it directly relates to and supports your project’s research question and aim. You should explain:

1. Why your research topic has been chosen by you (that is, why it is relevant)
2. What do we know already about this issue (succinct Chemistry theory)
3. How the variables might be measured

**1.1 Aim:** *[research relevant background scientific information to refine the research question/hypothesis and methodology].*  State your Aim.

**1.2 Research Question:** *and [develop a research question to be investigated]*

State your Research Question

**1.3 Hypothesis:** *[develop a hypothesis based on the research question for the investigation]*

State your clearly formulated and testable hypothesis (as mentioned before). It should mention DV, IV/s and controlled variable, and the link between them: “It was hypothesised that the….”. [Justifying - How to Write p 26-27].

**1.4** **Hypothesis Justification:** *[justify the hypothesis by reference to the literature]*

You will need to justify your hypothesis by referring to relevant Chemistry principles from your research. You can write this in a persuasive style. You should be trying to persuade the reader that your hypothesis is logically supported by Chemistry theory with links made between underlying concepts and you should aim at convincing the reader of your point of view.

* 1. **Orientation to the Design**

You should present a short overview (50 words) of your experiment and state your variables. [*Explaining* - How to Write p 20-21]

**Planning & Preliminary trials. To reduce the amount of writing in your report, this part can be omitted if you wish. It should be in your log book.**

• Introduction: What values you chose to try for your manipulated variable/s (eg masses of 0.1 kg to 0.8 kg)

• Method: What you did; and diagrams or photos as necessary.

• Results: Presented in appropriate form (tables, graph etc).

• Discussion: Could measurable results be obtained? Could you collect sufficient data? You are not expected to make a conclusion about the relationships between variables as outlined in the Aim, Research Question and Hypothesis. This is a discussion about the experimental design.

• Conclusion: How the original plan is to be modified in light of the pilot study.

Note: the next Section (Section 2) is the Method. At a university level there may be another Section in between called “Review of the Literature”. You would not need this.

**2. Method**

**2.1 Method and Materials**

Describe in detail the method you used to collect your data and organize your observations. Your report should be detailed enough for anyone to be able to repeat your experiment by just reading the paper, so keep this fact in mind when you write it. In other words, it has to be ‘Replicable’, meaning that someone else could repeat the experiment by following your method. It's always a good idea to include detailed photographs or clearly-labelled drawings of any device you made to carry out your research. You can also include how raw data is to be treated, that is, what formulae are applied.

One good approach to writing a method for the report is to have one member of the group say exactly what they are doing and another recording the words (straight into the computer if you’re fast at typing).

**2.2 Risk assessment** *[conduct a risk assessment and account for risks in the methodology]*

You must consider safety when designing your method and justify why the safety precautions (if any) are included.

**3. Results and Analysis**

**3.1 Results:**

*[present the quantitative and qualitative data appropriately]*

The collected results should be displayed in forms that are appropriate to your data; eg tables, photos. No doubt you have learnt how to present tables so they won’t be dealt with again here. The key is that the results presented should be chosen with discrimination; that is, don’t include mistakes or data unrelated to your hypothesis (eg air pressure, colour of the wires, brand of meter…).

The strength of a table lies in its ability to show large amounts of exact data. However, your data should be summarised here. If you feel that the full impact of the results aren’t shown in a table then put it in an appendix (but it is essential to refer to each appendix within the main body of the report; for example, ‘For the full data set, see Appendix B’). All tables, pictures and diagrams should be numbered and given a comprehensive title. Reference any you have copied from other sources.

**Table of Data**

1. **State** what you have measured and show sufficient and relevant raw data.
2. **Display** it in forms that are appropriate to your data; i.e. a table of temperatures and times and so on, appropriately labelled with all units of measurements. Include a title for each table which describes the data that is in the table e.g. Table 1: Time taken for…………….

**3.2 Analysis:**

*[process the quantitative and qualitative data to identify patterns and trends]*

Start by talking about what you did to the data (average, graph, correlations, …), why you did it and what you obtained by doing it. It must be in a logical order. This is an opportunity to identify any trends or patterns in your data, or examine any mathematical relationships in your data. Calculations such as averages, substitution into equations, gradients, intercepts - and so on - may be shown as necessary. If a large number of repetitive calculations (e.g. rate of change, solution concentrations, density etc) need to be performed, put one sample calculation in your report and then the rest can be performed and then placed in a table. Where numerous graphs or tables are used to extract main results (eg area under v/t graphs; slope of s/t graph), these graphs or tables should go in an appendix. The two sub-headings could be:

1. **Calculations**
* One example of each type of calculation should be shown. Calculations may include averages (means). This can be included in the report as an Appendix if it is too long for the body of the report.
1. **Graphs**
* Include a title for each graph which describes the data that is in the graph e.g. Graph 1 (or Figure 1): Note that the table name and graph name could be the same. The graphs should show all relevant trends, patterns and relationships.
* Graph discrete data as column graphs. The information on this type of graph should be represented in ascending order. Graph continuous data as line graphs.

**3.3 Error Analysis**

*[analyse the precision of the quantitative data]*

* calculate uncertainties;
* use rules to aggregate uncertainties

*[analyse the accuracy of the data by comparing the results with theoretical expectations]*

* state source of theoretical expectations
* calculate Ea and Er

You will need to undertake an error analysis. This could be as simple as a qualitative description or as complex as a full numerical error calculation. However, it is the logic that is important and some quantification of accuracy should be evident. As an absolute minimum I suggest that for single measurements (voltage of a cell) you use the measurement uncertainty rule of ± half-scale division (for printed scales like a ruler, voltmeter etc). For a ruler calibrated in mm, it would be ± 0.5 mm. For a digital scale, use ± smallest increment, eg a digital pH meter that reads to 0.01 pH units then the measurement uncertainty is ± 0.01 V. For multiple readings of the same quantity (eg time for the titre of a 20 mL aliquot of soft drink) calculate the mean, and the absolute uncertainty of the mean (xmax - xmin)/2. Then calculate percentage uncertainty. This is a big issue and too much to discuss here. I’ve attached a short note on error analysis and EEIs at the end.

**4. Discussion**

In simple terms, the Discussion is where you explain what you make of the Results you obtained. If you have done the Results & Analysis part well, your readers should already recognize the trends in the data and have a fairly clear idea of whether your hypothesis was supported. So – they know what to expect and you have to deliver it.

The Queensland syllabus makes it clear that for Year 11, the analysis / discussion / evaluation / recommendations of the EEI report should be between 800 and 1000 words, and for Year 12, between 1000 and 1500 words. However, you need to keep in mind that these are suggested word limits (they are merely “guidelines”) and the most important statement is in the task criteria which should stipulate “discriminating selection, use and presentation … to make meaning accessible…”. If you need more that 1500 words to make the meaning of your results “accessible” (understood) then so be it, provided you are “discriminating” as well and don’t waffle on. The Discussion is one of the key sections of the EEI. It is where you need to show evidence of critical thinking in interpreting your data in relation to your hypothesis and theory presented in your introduction. This is an opportunity to evaluate any trends or patterns in your data, evaluate any mathematical relationships in your data, to critically discuss various aspects of the experiment, such as: what generalisations can be made to support or refute your hypothesis, how the results relate to the Chemistry theory, the limitations of the result, the method used and possible improvements.

A caution: the genre for an EEI “Discussion” is not what you normally think of as “Discussion genre”. It is really a “persuasive exposition” – a form of argumentation when you argue your case with an anonymous reader whom you picture as trying to pick holes in everything you do and say (a “naysayer” or a highly critical imp sitting on your shoulder). The way you handle such an argument is described below. Nevertheless, a good way to handle the writing of the Discussion is to tell readers: what you are about to say, say it, and then tell them what you’ve said. It should flow logically so that the reader can easily follow your train of thought. The following paragraph topics should give you a nice flow. There is no need for any subheadings.

* 1. **Discussion & Interpretation**.
		1. **Introduction. Introduce this section by restating your Research Question.** Make a clear statement about what it was you were trying to find out. For example, “This investigation was aimed at answering the …”

**Restate your hypothesis and state whether it was supported or not supported.** This statement is usually a good way to begin the main part of the Discussion. You might begin by explicitly stating the relationships your data indicate between the independent and dependent variables. Then you can show more clearly why you believe your hypothesis was or was not supported. For example, “The hypothesis that an increase in temperature would ….was (was not) supported by the data.” This should be a valid and defensible statement based on the above analysis. If it is only partly supported say so and explain.

* + 1. **Summarise the results.** Include three or more pieces of experimental evidence that support your statement about the hypothesis. All of the evidence and examples must be specific, relevant and explanations given that show how each piece of evidence supports and convinces the reader of your hypothesis. Refer explicitly to selected data from the table/s and graphs. (Summarising - *How to Write* p 36-37) and identify any trends (patterns) in the data that support your claim (Interpreting - *How to Write* p 24-25. Elaborating - *How to Write* p 16-17).
		2. **Discuss the error analysis** (*Analysing* - *How to Write* p 2-3) by discussing the reliability and validity of the experimental process using evidence such as the quality of the data (as quantified in this error analysis).
		3. **Identify all inconsistent results (anomalies and outliers) and attempt to explain the source of these. Acknowledge any anomalous data or deviations from what you expected.** Recognize that saying whether the data supported your hypothesis or not involves making a claim to be justified. As such, you need to show the readers that this claim is warranted by the evidence but that you may need to qualify your conclusions sufficiently. For obvious reasons, your readers will doubt your authority if you (deliberately or inadvertently) overlook a key piece of data that doesn't agree with your claim that the hypothesis was or was not supported. So you have to pre-empt their refutation of your data with your own rebuttal. For example, you may need to point out “However, at higher temperatures the relationship no longer seems to hold ….” Then identify data that is anomalous or that you are discounting (and why). If you don’t point it out and the reader notices it then ‘critical evaluation’ is lacking. The idea is to get in early and acknowledge where your data could be lacking and say why it really is okay. This is good “argumentation”. (Providing Evidence - *How to Write* p30-31). Note: an ‘outlier’ includes data that seems to be a bit too far away from the trendline (in a graph). An ‘anomaly’ is data that is plainly wrong (possibly just a mistake).
	1. **Limitations caused by errors and uncertainties.**

*[evaluate the effectiveness of the methodology]*

**Evaluate experiment** (Evaluating - *How to Write* p 18-19) **and method to identify and explain sources of error and provide solutions** (Solving Problems - *How to Write* p 34-35).Identify **up to 3** problems relating to design **and up to 3** relating to method, state why they were problems (i.e. how did this influence your results), provide a detailed description of how **each** of these problems could be fixed and how the modifications will improve the quality of the data.

This is a key aspect of the discussion and one that is generally done poorly. It is where you can get extra marks and make your work really stand out. You will need to review your error analysis. Begin by summarising the error analysis done in the previous ‘Analysis’ section of your report and then discuss which measured quantities limited the accuracy of the result, and why, and what could be done about it in the future. My advice to students is always:

* State 3 things in the **design** that were a problem (eg air resistance may have had an unexpected impact); other variables you should have controlled but didn’t realise until later; you were not using the appropriate instruments; the variables you chose were not linked by cause-and-effect as you thought, but by some hidden variable.
* Explain why these are problems (eg air resistance slows object down)
* Describe how the problems can be fixed (eg use smoother or more dense object)
* Justify why that design change will work (eg smoother means less air resistance because …)

**Now:** repeat these 4 points for problems related to the **method**. This might include the number of trials, too limited range of data, limitations of the instrument, need to remeasure anomalous data or outliers that only became apparent later on, and so on.

Whatever you say, don’t include mistakes you made. Students usually say “use an electronic photogate” or some such. If you do (and it is pretty obvious) say how the measurement uncertainties will be reduced and give an example. More often than not students get a “C” grade here because they think they have finished the report and just put a few meaningless comments in about more accurate or digital thermometers and voltmeters, or videoing the experiment. Be warned! (Analysing - *How to Write* p 2-3)

**4.3 Improvements and extensions**

*[identify and justify possible improvements and extensions for the experiment]*

* These improvements or extensions to the experiment must be logically derived from the analysis of the evidence. (Making Recommendations - *How to Write* p 28-29).

**Derive conclusions, based on your findings, about the process you're studying**

Discussions must relate the experimental issues to Chemistry theory. That is, is the link between your data, the theory and your claims a logical one? Do you have to modify anything you said in the introduction or justification in light of your findings? You need to silence a critic who could say “it’s not logical to draw that conclusion because…” by showing that it is logical process you have undertaken. In other words, make it clear that you have made a logical and reasonable argument from valid and accurate data supported by trustworthy and relevant theory to generate logical conclusions. Bingo, argument over, you won!

**Relate your findings to other work in the same area (if you can)**

Is there something about your project that adds to further understanding in Chemistry? You may like to suggest that your experiment dealt only with a narrow sub-set of possibilities and your generalisation comes with that caution. But you could say that it may apply more broadly. For example, if your hypothesis dealt with the changes in resistance with temperature, then try to make some generalizations about it applying to other materials. Perhaps you could point to a similar experiment or study and contrast your results and conclusions. Perhaps you have purposely chosen to investigate an issue (maybe even a controversial one) that is somewhat less ‘resolved’ and you can use your own work to add to the debate.

**Explore the theoretical and/or practical implications of your findings**

You could end by reflecting on if your work tells the reader something new about the Chemistry concepts under consideration. Alternatively, you could speculate on the medical, industrial, entertainment, scientific or commercial implications of your findings - in other words, what could your discoveries help people to do? In either case, the aim is to make your audience think it was worthwhile reading your work.

**Future possibilities and recommendations**

The syllabus talks of ‘exploration of scenarios and possible outcomes with justification of …recommendations’. For this you should note further related investigations that this experiment could lead to. Don’t just say wishy-washy things like ‘try other variables’, ‘be more accurate’, ‘use a digital multimeter’ and so on. These recommendations would only be valid if you can justify them. This is a good chance to show some more critical thinking. Think of ways to modify, refine, extend or redirect it with an example that would further answer your research question. A reference to some other research would be a strong finish.

***5. CONCLUSION***

*[draw a conclusion which addresses the research question or hypothesis]*

* State the essential conclusion or conclusions you have drawn from the experiment. This means stating all main results and any trends. (Concluding - *How to Write* p10-11)
* State whether or not the hypothesis has been supported and why.
* State whether or not your aim was achieved and why.

In persuasive or argumentative writing – which is what this report is – you want to use your closing words to convey the main point of your writing. The conclusion has to be very strong and leave the reader solidly understanding your position. A good way to start is by summarizing your results. Make sure not to introduce anything that wasn't already mentioned in the previous parts of your paper. You should state very briefly the essential conclusion or conclusions you have drawn from the experiment. It should satisfy the statement set out in the Aim at the beginning and must clearly address the stated hypothesis. Be sure to include any conditions that apply to your result (eg ‘at constant temperature’). It is important not to overstate what you can rightly claim as a result of the experiment. Statements like ‘the results supported…’ are more justifiable than ‘the results proved…’. Make it clear that you have considered arguments against your claims (if you really have) and how you have rebutted them (if you have). This is the essence of argumentation.

**6. Appendices**

This is where you place information that is not essential to explain your findings, but that supports your analysis (especially repetitive or lengthy information), validates your conclusions or pursues a related point. Sometimes excerpts from this supporting information (i.e. part of the data set) will be placed in the body of the report but the complete set of information (i.e. all of the data set) will be included in the appendix. Examples of information that could be included in an appendix include figures/tables/charts/graphs of results, statistics, photos, lengthy derivations of equations, data sheets, or computer program information.

There is no limit to what can be placed in the appendix providing it is relevant and reference is made to it in the report. The appendix is not a place for all the semi-interesting or related information you have gathered through your research for your report. That can go in your journal or logbook. The information included in the appendix must be directly relate to the research problem or the report's purpose. It must be a useful tool for the reader. Each separate appendix should be lettered (Appendix A, Appendix B, etc).

**7. Bibliography or References**

 This list should include any documentation that is not your own, such as books or articles that you used. Guidelines for a bibliography and referencing can be found on the internet but just check which style (APA, Harvard…) your teacher expects. It should be on the task sheet or there may be a whole-school approach available on your intranet. Material is placed in the body of your report should be acknowledged and referenced appropriately.

**8. Acknowledgments**

In this section you should give credit to everyone who assisted you. This may include individuals, businesses and educational or research institutions. Identify any financial support or material donations you may have received.

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**Extended Experimental Investigation**

***Draft Report - Feedback Checklist***

 Name:

|  |  |
| --- | --- |
| **Aspect** | **Areas that might need improvement are marked by a cross ⌧** |
| Task | 🞎 awareness of the purpose of task. |
| Title page | 🞎 completed with an accurate, concise and informative scientific title |
| Research Quest. | 🞎 stated as general question that is linked to the title beginning with “how”, “what” or similar |
| Aim | 🞎 rewords the RQ to make a statement of the purpose of the investigation, beginning with “To”  |
| Hypothesis | 🞎 clearly states the variables🞎 links the variables with terms that show the expected relationship between variables |
| Hypothesis Justification | 🞎 uses science theory, facts and principles that are appropriate and correct🞎 directly related to the hypothesis (no extraneous matter)🞎 clearly worded using topic sentences and linked ideas🞎 provides a reference for your comment or claims |
| Orientation or Expt design | 🞎 outline briefly the experimental design  |
| Method | 🞎 past tense, 3rd person, numbered steps🞎 sufficient detail for someone else to repeat it🞎 terminology correct🞎 labelled diagrams/photos as appropriate🞎 safety precautions as appropriate |
| Results & Analysis | 🞎 states what has been measured 🞎 show sufficient and relevant raw data🞎 have correct units and symbols🞎 displayed in tables🞎 displayed in graph form if appropriate, with axes/labels/title correct🞎 tables and graphs labelled🞎 graphs show appropriate trends relevant to the hypothesis🞎 analyses the accuracy of the data by comparing the results with theoretical expectations (if appropriate) |
| Discussion | 🞎 restates hypothesis🞎 states whether it was supported or not supported🞎 summarizes results related to hypothesis 🞎 identifies any trends (patterns) in the data that support your claim🞎 draws a valid conclusion based on analysis 🞎 brings all finding together (synthesizes) beyond merely restating the findings🞎 discusses the reliability and validity of the experimental process using evidence such as the quality of the data 🞎 identifies all inconsistent results (anomalies and outliers)🞎 attempts to explain the source of all inconsistent results🞎 provides solutions to problems with design or method🞎 improvements or extensions to the experiment are logically derived from the analysis of the evidence🞎 concludes with critical analysis of investigation including interpretations🞎 provide follow-on investigations that could be undertaken (with reasons)  |
| Conclusion | 🞎 states the essential conclusion or conclusions drawn from the experiment. 🞎 states all main results and any trends. 🞎 states whether or not the hypothesis has been supported and why🞎 states whether or not the aim was achieved and why |
| References | 🞎 shows correct referencing of sources (uses in-text referencing to acknowledge the source of researched information)🞎 no evidence of plagiarism  |
| Bibliography  | 🞎 is included🞎 sufficient number of sources🞎 referencing style is consistent and without errors |
| Appendices | 🞎 correctly labelled🞎 referred to in body of report |
|  | **GENERAL COMMENTS** |
| Structure  | 🞎 generic structure follows style guide🞎 body of report has clearly defined paragraphs and each clearly introduced to show an understanding of them |
| Language | 🞎 vocabulary has appropriate level of sophistication🞎 precise or scientific terms used appropriately (words highlighted need to be replaced)  |
| Sentences | 🞎 sentence length neither too long nor too short🞎 sentences show variety in form and length🞎 consistent use of active/passive voice and tense🞎 appropriate punctuation using a full stop or semicolon, not always a comma |
| Technical  | 🞎 correct use of apostrophes, capitals, commas, grammar. |
| Paragraphs | 🞎 consistently contain a topic sentence (usually at beginning)🞎 consistently contain a concluding sentence🞎 ideas and paragraphs linked well |
| Spelling | 🞎 spelling is correct🞎 a few spelling errors are circled. |
| Length | 🞎 appropriate length, neither too long nor too short |
| Presentation | 🞎 formatting makes report easy to follow🞎 has clean layout and neatness |

RW 25 May 2017

Teacher’s signature: Date:

Dealing with errors

To understand the recording and analysis of errors and uncertainties, consider this hypothetical experiment. In it there are two types of calculations:

1. the *uncertainties surrounding the measurements* that are estimated and ‘propagated’ through various calculations to the final result;
2. the difference between your observed result (O) and the accepted value (A). This difference is often called *discrepancy* or more commonly *error*.

**For example, imagine titrating a 20 ml aliquot of soft drink against 0.105 M NaOH.**

**Experiment:** How accurate is the stated titratable acidity of soft drink?.

**Measuring devices:** burette ± 0.05 mL, pipette 20.00 ± 0.05 mL

**Results:**

|  |  |  |  |
| --- | --- | --- | --- |
|  | Trial 1 (s) | Trial 2 (s) | Trial 3 (s) |
| Titres | 21.05 | 22.15 | 22.00 |

**UNCERTAINTY CALCULATIONS**

Pipette aliquot of soft drink = 20.00 ± 0.05 mL (according to manufacture’s specification) = 20.00 ± 0.25%

Concentration of base = 0.105 ± 0.5%

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Trial 1 (s) | Trial 2 (s) | Trial 3 (s) | Mean(s) | Absolute uncertainty of the meanδ | Percentage (relative) uncertainty of the mean%δ=  |
| Titres | 21.05 | 22.15 | 22.00 | 21.73 | = ± 0.55 | = 2.53% |

**Calculations:** (propagation of uncertainties):

Cacid = = = 0.114 M ± 3.78%

**DISCREPANCY OR ERROR CALCULTIONS**

**Accepted value** (A) for titratable acidity (TA) of Golden Circle Creaming Soda = 0.119 M;

**Observed** value (O) from titration = 0.114 M

**Absolute error** (Ea) = |O−A| = |0.114 − 0.119| = 0.006 M

**Relative error** (Er) = Ea/A × 100% = 0.005/0.119 × 100 = 4.2%

**Note 1:** the relative error is 4.2% which is more that the uncertainty (3.78%) in the result.

**Note 2:** the relative error of 4.2% for the observed value is outside the range for the accepted value so we can say the experimental result can’t confirm the stated value of 0.119 M.

**Rules:**

* adding and subtracting: add absolute uncertainties (δ)
* Multiplying and dividing: add % uncertainties