Concrete Advice on Writing an Abstract

O Abstract, my Abstract, so misunderstood,
when not written in past tense, that is the worst.
O Abstract, my Abstract, it's for your own good
that though written last, hence, you'll be read first.

OK, you see that there? Not only is it bad poetry (though I'm partial to the internal rhyme), but it's a perfect example of what NEVER to do in an Abstract.

I'm not saying I've had a big problem with people turning in Abstracts that rhyme (what an interesting but odd problem that would be); however people do sometimes try to make them a bit cutesy; and though no part of a lab report should ever be cutesy, the Abstract is, bar none, the worst section to put in fluff or flowery writing or anything of that ilk.

Here's the deal.

The Abstract is intended to be a summary of the most important points of your entire experiment, from beginning to end. **This is why you should write it last.** Probably the best approach to writing your Abstract it, in fact, to go through the lab report from Introduction through Discussion, and summarize each section in 1-2 sentences (depending on the complexity of the experiment). In Chemistry I, I usually tell people to use 5 sentences, which would be aligned as follows: 1) Introduction; 2)Purpose/Procedure; 3) Results; 4) Conclusion; and 5) Discussion. However this is a guideline and not a rule. Sometimes it will definitely take more than one sentence to summarize the important points from each section. However, if you *can* summarize the important points from a section in one sentence, by all means do so.

Why are you summarizing the whole report? For a very simple and practical reason. Any given week, there are hundreds of papers published in scientific journals around the world. JACS (*The Journal of the American Chemical Society*), for instance, comes out about once a week, and each issue contains 8-12 papers on work people are doing. Each paper is essentially a lab report written by the scientist who conducted the research. That's just JACS. ACS publishes about 35 more journals too. Not all of them are as frequent as JACS; but it's still an enormous amount of research being published. Further, ACS is not the only American publisher of chemistry research; and further still, other countries also have peer-reviewed scientific publication systems; for example the Royal Society in the UK. The same basic situation exists in physics, naturally; especially if you consider the far-flung variety of research topics in physics.

The point is that if you are a working scientist, it is impossible for you to read all the work being published in your own field, let alone other people's fields. There are simply not enough hours in the day. Yet it is through communication and collaboration that the scientific process builds up its ideas. Peer review is important. Having access to the latest research is important. This is especially true in this age where scientists tend to become highly specialized. In my own research, I may suddenly need to know what's going on in a field I haven't specialized in, so I need to know what's out there. But I'm simply not going to have time to do it all.

Enter: The Abstract.

The purpose of the Abstract is to provide the reader a concise but thorough summary of the important points of the experiment. I should be able to read the Abstract and know, in a nutshell, what your experiment was about, why you did it, how you did it, what your results were, how well it worked out, and what major issues impact your certainty.

I should be able to read your Abstract, know what's going on in that area, and not have to worry about reading the rest of your paper if it's not of interest to me, or necessary for my own research. (Note: Like the rest of the paper, the Abstract is written after all the work it describes, and therefore absolutely *must* be written in past tense. It also *must* be the most professional, businesslike section of the entire professional, businesslike report. Anything else is just bad form.)

Your Abstract must give a clear and full summary of your work, as it may be the only thing your reader reads. Your Abstract must be as concise as possible, or you have defeated the purpose of the Abstract.

That being said, you certainly want people to read your work; so you should also think of the Abstract as a sort of sales pitch. Not in a cutesy, gimmicky way; there is no place for that in a lab report, which is a very businesslike document; let alone in the Abstract, which is the most businesslike section of the lab report. Also, you should not come out and say, "You should read this because..." which is tactless, and is simply not done. Allow your work to speak for itself. Take it seriously, treat it as important, and hopefully your reader will do the same in response.

I will provide more suggestions and guidance in the post entitled "Good Abstract, Bad Abstract;" but I feel a need here to comment on a glaring error that many students make despite the fact that I tell every single class that this is my single biggest pet peeve with regard to the Abstract.

ALWAYS make sure you include the actual results of the experiment in your Abstract! If that means a numerical value--it had better be there! If that means the identity of an unknown--you had better state it! If it means a comparative analysis--you had better do it! Remember, your reader may only read your Abstract; so if you leave out the results of the experiment, you have left out the whole point. The only thing worse than not having the results in the Abstract is not having the results in the Results (which--believe it or not--also happens sometimes). In the "real world," if you don't show the consideration of putting your results in your Abstract, not only will you have lost a reader on that paper; you will probably have lost that reader...period. Plus, it makes me really, really annoyed; which probably should not be your ideal way for me to start out my reading (and grading) of your paper.

Finally, though technically it should appear at the beginning of the post, I've written an abstract of this post below (yes, abstracts can be, and are, written for things besides lab reports). This abstract does exactly what an abstract should do. It gets the full point across, even though not all the details are presented; and it does so without wasting words.

ABSTRACT: When writing an Abstract, be thorough in your summary of the important information, since your readers may read no more of your report than this section. But be concise, because your busy readers are not likely to even glance at a wordy Abstract. Finally, make the most of your opportunity to impress your readers with the quality of your work by presenting it in a professional manner.

Good Introduction, Bad Introduction

In the old *Animaniacs* series, there was a segment called "Good Idea, Bad Idea" that was always fun. The title essentially gives you the premise, or you can go on youtube and search for clips. (My personal favorite is, "Good idea: playing catch with your grandfather. Bad idea: playing catch *with* your grandfather.")

Anyway, they're not as funny, but here are some "Good Introduction, Bad Introduction" tips. In each case, I'll write an excerpt from a "good" introduction and an excerpt from a "bad" introduction of the same experiment, then explain what makes the difference. Note that in each case, the "good" example is how I would write it; and the "bad" example is "inspired" by the many lab reports I've read through the years.

EXAMPLE 1: From the first paragraph of the Introduction for a chemistry experiment

Good Introduction: A chemical reaction is said to be "reversible" when the products are able to re-form the reactants with relative ease under given conditions. In any closed system containing a reversible reaction mixture, regardless of initial amounts of reactant and product, the rates of the forward reaction (reactant to product) and the reverse reaction (product to reactant) must eventually become equal. This is because the rates must always approach each other. For example, if only reactants are present at the beginning, then the forward reaction will proceed quickly, while the reverse will not be happening at all, initially. As reactants diminish, however, the forward reaction will slow; and as products build up, the reverse reaction will increase in rate, since the rate of a reaction depends on concentration. Both trends will continue until the rates are equal, at which time the amounts of reactant and product will also become fixed, since reactant is generated exactly at the same rate as product. The fixed concentrations of the reactant and product also fix the rates at this point, so the rates will also remain equal. This condition, called "chemical equilibrium" or just "equilibrium," will remain until an external stress that undoes the established balance is imposed upon the system.

Bad Introduction: Some reactions can go backwards. When they do, they reach equilibrium, but that can get thrown off.

THE DIFFERENCE: Setting aside the informality of tone and the very poor diction in the Bad case (which is also bad), the serious problems here are that while the Good one eases the reader into the topic by starting out with a basic definition and then building to the point, the bad one simply makes an abrupt, out-of-context, unjustified statement, and follows it up with...nothing. The Good one provides enough explanation for the reader to follow the ideas. The Bad one really provides no explanation at all; it simply states things--and not very well, at that. Compare the level of detail in the two examples. Considering they are supposed to relay the same information, which one does a more thorough job?

EXAMPLE 2: From the second paragraph of the Introduction for a physics experiment

Good Introduction: In this lab, Hooke's law is used to measure the spring constant of a spring by measuring the displacement of the spring when weights are added. Once the spring constant has been determined so that the maximum kinetic energy of the spring (KE_{max} = (1/2)kA^2) is known, the effect of damping on the harmonic oscillation of the spring is analyzed by measuring the decrease in amplitude over time. While damping does reduce the amount of energy in the spring over time, the law of conservation of energy clearly implies that the "missing" energy has simply been converted to other, unusable forms. In this case, it occurs due to the presence of nonconservative forces, mostly friction and air resistance; though other losses due to the production of sound, heat, or other forms of "thermal" energy are likely a significant factor. The approximate rate of energy "loss" in the spring can be modeled from the amplitude data collected. Understanding how a spring (or a spring analog, i.e. anything that obeys Hooke's law) "loses" energy over time could be an important factor both in cases where the minimization of damping is desirable, as well as applications in which critical damping is the goal, such as in the shocks on a car.

Bad Introduction: In this lab, the damping on a spring will be measured by calculating how the amplitude decreases over time. Spring constants, which basically measure how "strong" a spring is, will be determined using Hooke's law. Elastic limits are where a material leaves the "elastic" region of the graph, meaning it doesn't obey Hooke's law. It goes into the "plastic" region then. They can also have a breaking point, which is obviously where it breaks, and the graph ends. Even though energy is conserved is a law, sometimes you lose energy. You're not really losing it though, because it just becomes sound or heat, thanks to things like friction. When simple harmonic motion, which is how a simple harmonic oscillator moves, loses energy, it is damped. All springs are really damped. Nothing is perfect. The equations we will use in this lab are F = kx and PE = (1/2)kx^2. As the spring bounces up and down, kinetic energy is converted to potential energy and vice versa. It's elastic potential energy since it's a spring.

THE DIFFERENCE: Once again, setting aside the informal tone and diction, and also setting aside the use of "we" at one point and the use of the future tense, it is fairly obvious that the imaginary student writing the Bad Introduction was haphazardly throwing in information in a blind effort to put everything in and get full credit. There is no reasoned structure; no progression of ideas to follow; no discernible point. Here, unlike the first example, it is not really an issue of the level of detail so much as the *choice* of detail and the *arrangement* of the detail. Notice that the disjointed arrangement of the details in the Bad example render important points seemingly irrelevant, or at least bizarrely out of context. "All springs are really damped," for example, more or less comes out of nowhere. Worse, it is followed by the wholly unnecessary and overly opinionated comment that, "Nothing is perfect." I won't try to make a list of perfect things; but without question, this Bad Introduction would not be on that list.

Good Purpose, Bad Purpose

Below are some examples of common errors students make in Purposes; each followed by an improved example.

EXAMPLE #1

Bad Purpose: To make a reaction between copper (II) sulfate and iron.

Problems

- It is not a complete sentence.
- There is no hint as to why the experiment was done. "To make a reaction" is not only too informal a phrase, it is also too vague. Why would you carry out this reaction? Were you just observing it? Did you do anything with it? Did you try to determine anything?
- There is no statement of method; and indeed, whatever this experiment may have been, its purpose clearly had to be something deeper than simply to perform the reaction, which may have been the core of the procedure, but certainly cannot have been the whole point. So alternately, the above bad example could be interpreted as having no statement of purpose, and a partial statement of method.

Better Purpose: The purpose of this experiment was to analyze the reaction of copper (II) sulfate with iron by determining the percent yield of the copper produced in the reaction.

Notes: There is nothing really *wrong* with this Purpose. It is clear and precise; it tells you what the goal of the experiment was, and it tells you how it was to be accomplished. It could still be improved, however, by the inclusion of a secondary goal, which could again be useful in the instance that the primary goal was not accomplished with much success.

Even Better Purpose: The purpose of this experiment was to analyze the reaction of copper (II) sulfate with iron by determining the percent yield of the copper produced in the reaction. A further purpose was to gain understanding and experience in the use of stoichiometry through its use in achieving the results.

Notes: Again, there is nothing wrong with this Purpose. It has everything it should, and a secondary educational goal. It could be improved slightly, however, by making it a bit more succinct.

Best Yet Purpose: The purpose of this experiment was to gain an improved understanding of stoichiometry by using percent yield to analyze the reaction of copper (II) sulfate and iron to produce copper and iron (II) sulfate.

Notes: This Purpose, while being shorter than the previous, contains just as much detail. Further, it is the most complex of the three examples, because it combines both the goals stated in the second example into one goal. When you can do this, it is not just acceptable; it is the most sophisticated way of writing a Purpose. It still provides the benefit of multiple purposes; you just have to look at degrees of accomplishment instead of separate accomplishments of purpose.

Ultimately, since it is your experiment and your report, you have to decide whether it is better to keep your purposes separate or to try to combine them. It comes down to three issues: whether it makes sense to do so; whether it is advantageous to do so; and how natural or awkward it is to do so.

Honestly, the Purpose is really not too difficult to write well, so I hope you now have enough to be getting on with.

Good Procedures, Bad Procedures

Following is a good and bad example of Procedures sections. The example is from a chemistry lab.

BAD PROCEDURES: First, as always, gloves, aprons, and safety goggles were placed upon hands, bodies, and eyes, to avoid contamination of the experimenter's body and clothing. A 100 mL beaker was cleaned and dried, and weighed while it was empty. An electronic balance was used to measure out what was supposed to be 6.25 g of CuSO4·5H2O, but what turned out actually to be 6.27 g of CuSO4·5H2O. A graduated cylinder was washed and thoroughly rinsed, and then 25 mL of distilled water was measured into it. The distilled water was then poured carefully into a 100-mL beaker that had also been carefully washed and rinsed. The CuSO4·5H2O crystals were then carefully transferred into the beaker containing the water. A rubber policeman was placed on a stirring rod. The stirring rod was used to stir the mixture of water and CuSO4·5H2O until the CuSO4·5H2O had completely dissolved. The beaker containing the dissolved CuSO4·5H2O was placed on a hot plate and the hot plate was turned on to a setting of 4. Meanwhile, 1.12 g of Fe filings were supposed to be weighed out using the scale and a piece of weighing paper, but 1.11 g of Fe filings were weighed out instead. The instructor was asked if this was acceptable, and it was determined that it was. The iron filings were

then transferred slowly into the warm solution of $CuSO_4 \cdot 5H_2O$ while stirring constantly with the stirring rod that had the rubber policeman on it. Stirring continued for 10 minutes, then the hot plate was turned off and the solution was allowed to cool for 20 minutes. Decanting, which means to pour a liquid out of a container using a stirring rod as a guide, was practiced with water during this time. Then the liquid was decanted off the reaction mixture by pouring it out of the beaker along the stirring rod. This left the solid at the bottom of the beaker. 10 mL of distilled water was measured in a graduated cylinder and poured into the beaker containing the solid. This was to rinse excess solution off the solid. The beaker was swirled vigorously and the contents were allowed to settle. The water was then decanted off the solid by pouring it down a stirring rod. Another 10 mL of distilled water was measured in a graduated cylinder and poured into the beaker containing the solid. This was to rinse off the solid even more. he beaker was swirled vigorously and the contents were allowed to settle. The water was then decanted off the solid by pouring it down a stirring rod. The solid was spread out on the bottom of the beaker and the beaker was placed in the hood to dry. Gloves, goggles and apron were removed, the counter was wiped down, and hands were washed. The next day, the beaker with the solid was weighed. The mass of the empty beaker, since it had been recorded before, could be subtracted from the mass of the beaker and the solid to obtain just the mass of the solid. The percent yield was calculated.
I hope the problem here is obvious. There is *way* too much unimportant information given here; and there is virtually *no* effort to keep things concise. Remember, you only need to include information that is relevant to the outcome. Thinking about what was actually happening in this experiment...

- Are the safety precautions unusual, and thus worthy of mention? Doesn't the reader know what gloves, aprons, and goggles are for? And for that matter...doesn't the reader assume that you will take standard safety precautions?
- Wouldn't the reader assume that if you are using equipment, it is appropriately clean?
- Does it matter what the instructions had called for as opposed to what the student actually measured out? In other words, how does what you were "supposed to do" affect *what actually happened*?
- Are things listed (practicing decanting, washing graduated cylinders) that do not need to be mentioned at all, because they have no impact on the outcome?
- Are things written in as compact a manner as possible, or are things repeated that don't need to be?
- Also note the blatant awkwardness of some things. The first sentence is a whopper--and yes, I have actually read things like that before. Another totally unnecessary awkwardness is the sentence that ends, "...and hands were washed."

GOOD PROCEDURES: A clean, dry 100-mL beaker was tared. 25 mL of distilled water was added, followed by 6.27 g $CuSO_4 \cdot 5H_2O$, which was a blue crystalline substance. This mixture was heated with a hotplate on a medium setting, and stirred using a stirring rod with a rubber policeman attached, creating a blue solution. 1.11 g Fe filings, which were small, dark gray, and metallic, were slowly added with stirring. After reacting with constant stirring for 10 minutes, the mixture was cooled, and the liquid, now a darker, murky blue, was decanted. The copper-colored solid product remaining in the beaker was washed by adding 10 mL distilled water and swirling vigorously, followed by decanting the water after allowing the contents to settle. This wash was then repeated. The solid was spread out in the beaker to aid in its air-drying overnight. The beaker with the product was then weighed, and its tared mass subtracted, to obtain the mass of the product and the percent yield.

Notice the efficiency of the language here as compared to the first example. Vocabulary helps here--"tare" is a great word to know. Also note that undue repetition is avoided. Further, if you read carefully, you will note that this second example, despite being less than half the length of the first one, actually contains *more* relevant information. Observations are seamlessly worked in; and even a few brief explanations of the rationale for certain procedures are given. These explanations (note the one about why the solid was spread out at the bottom of the beaker), while not necessary, are at least potentially useful in helping the reader understand what was going on. The reader may wonder, in other words, "why did they do that?"; and the writer here has anticipated that and given the answer. The elaborate and mostly unnecessary explanations in the first example, on the other hand, go into tedious detail explaining things that really don't need to be explained.

Fortunately, once you have the knack for writing a good Procedures section, it is fairly easy to do. And again, remember the following principles:

1. DESCRIBE WHAT YOU ACTUALLY DID
2. BE AS CONCISE AS POSSIBLE

Results: Achieving a Good Outcome

The Results section is the centerpiece, the main course, the nucleus--whatever metaphor for central importance you feel like using--of your lab report. It is where all the "action" of the lab report really takes place. Everything before it has built up to this section; everything after it looks back to this section.

If a lab report is a meal, then without a good Results section, all the stuff that comes before it is a pointless, unsatisfying appetizer for a main dish that never arrives; and everything that comes after it is a sad and largely irrelevant dessert of bad icing slopped on no cake at all.

For those of you who quickly tire of metaphor, the Results section is critically important to a successful lab report!

Unfortunately (and somewhat alarmingly), the most common problem with the Results section is simply not putting everything into it that should be there. Therefore, I will try to clarify exactly what should be in a good Results section, broken into three prioritized categories: "Must Have," "Could Use," and "Would Be Nice."

First, three terms you should understand:

(raw) data-measurements, observations, information collected during the experiment
(final) results-what you get by processing the data as prescribed, including numerical answers, identifications of unknowns, and other "final" sorts of outcomes
interpretation-what your results mean

and now...

MUST HAVE--as the heading suggests, your Results must have the following!

- All significant data and observations. Copious amounts of raw data--for example, if you have several pages worth of time trial data--may be included as an appendix to the report; but any data significant to understanding the outcome of the experiment must be presented in the Results section.
- A clear explanation of every significant method of processing the data. This includes a sample calculation for every type of significant calculation performed. You may exclude simple, standard computations such as unit conversions.
- All final results--in other words, what you were supposed to be finding or determining in the experiment. This includes all final numerical results, all final interpretations or identifications required, any and all graphs required, and anything and everything else you were supposed to determine.
- A clear explanation of how the final results were obtained, if more than the above description of methods is necessary.
- A clear interpretation of the final results--what do they mean? Essentially, what do you conclude from the outcome of the experiment? (This is a separate question from those addressed in the Conclusion!)
- A clear comparison of your results to the expected results; quantitative when possible. Percent error, when applicable, should always be presented whether your instructions specifically ask for it or not.
- A general, but definitive, assessment of the results--were they good? Bad? Reliable? Dubious? Expected? Shocking? Note that in the Results section, only a general justification of this assessment is needed, because the last two sections will focus on a more detailed assessment of the outcome. You can allude to your upcoming justification, or at most, make a very generalized statement of justification, but leave the details of the justification for the Conclusion and Discussion.

COULD USE--these are things that should be included as often as possible

- Tables, tables, tables! Whenever possible, report both data and final results in tabular form. It makes it look neat and professional; and more importantly, it makes it very easy for your reader to locate the pertinent information and follow your work. Not using tables when you could is likely to annoy your reader; and if your reader also happens to be your grader, annoyance is probably best avoided.

- Transitions, transitions, transitions! There are four stages to the Results: presentation of data; processing of data; presentation of results; and assessment of results. There should ideally be smooth transitions from each of these to the next, as well as from the previous section (Procedures) to the next section (Conclusion). For example, beginning the Results section with a table is very jarring. Proceeding directly from a table into sample calculations is also jarring; as would be going directly into another table. The reason to use transitions is bigger than just to avoid jarring your reader, however. You really want your reader to follow your thought process. Therefore, you should be using transitions to explain what the reader should be looking at in those tables; or what the reader is going to see demonstrated in the sample calculation.
- Graphs. Of course, if a graph is required, it is a "Must Have." But even when a graph is not required, if producing a graph is *sensible*, then it is definitely a good thing to do. Note that it is *not* always sensible to make a graph out of data. If your measurements consist of one measurement each of the apparent masses of six different samples in and out of water, there is probably nothing useful for a graph to reveal. On the other hand, if you are measuring the period of pendulums with six different lengths, a graph might reveal an important trend. Bottom line: graphs are neat, but use your noggin before using a graph you have not specifically been asked to provide.
- Graphics. We are not talking about clip art (which is a major BAD) or cutesy drawings or anything that does not serve the specific purpose of furthering your reader's understanding. We are also not talking about things your reader probably doesn't need explained, like a diagram showing how to read the volume in a graduated cylinder. What we are talking about is images of whatever variety and format that serve to clarify something that would otherwise be unclear, or take an inordinate amount of writing to make clear. A good example would be a free-body diagram in a physics lab report; but also note that sometimes, free-body diagrams are actually "Must Haves." Another example might be a diagram of a spectrum observed during a chemistry experiment, though again this might be a "Must Have." Ask yourself: will it help my reader understand what I am saying? If the answer is "yes," put it in. If your answer is "no," don't put it in. In fact, if your answer is even just "not really, but it's cool," then don't put it in; at least not in the Results. The Results section is not the place for that sort of "fluff." If it's that cool, work it into your Introduction instead.

WOULD BE NICE--things you don't always need, but that are nice touches when you add them

- Data connected to a procedural flowchart. This doesn't always work, but when it does, it's really nice. You lay out a flowchart that shows the different stages of the procedures, and write in it the results associated with each stage. When it works, this is a very effective and, dare I say, "pretty" way of presenting your data, because it binds it so neatly to the Procedures and thereby gives the report more of the feel of a consistent whole.

- Clean, formatted calculations entered on the computer as opposed to written by hand. If you can't figure out how to make it sensible and "pretty" on the computer, it is perfectly acceptable to write it out by hand. But if you have an equation editor in your word processor, or can otherwise have your calculations printed out nice and neat and clean, the effect on the look of your report is unparalleled. It stops looking like a high school assignment at that point, and looks like what you're training for--a serious, scientific, academic paper.
- Pictures. Diagrams or pictures of equipment or set-up belong in the Introduction or possibly the Procedures, depending on the situation; so the pictures here are something else and certainly aren't always appropriate, nor are they ever truly necessary. However, if part of your results includes something that is very visual in nature--a chromatogram, for instance; or even just a final product--a picture accompanying your description can be a very nice touch. Note: if you want to do this, it is best to have an actual picture of your own experimental artifacts or results; so you would just need to clarify with the instructor that it is OK to bring a camera and take some pictures.

Good Conclusion, Bad Conclusion

Let's just jump into the examples.

BAD CONCLUSION: The purpose was accomplished. It was very valid and I am confident in my results. The results were mostly accurate, with only -48.5% error. The results could not be precise because only one trial was done. The experiment worked just like we expected. A few sources of error were present but did not matter.

Maybe you're laughing. I hope so. But the truth is that I have read many a Conclusion that had this much sense and substance to it. Sometimes they even have less. Many people like to leave out anything about the purpose being accomplished.

Let's just start with the first sentence; which should not be the first sentence. In a real lab report, your reader will not read your Conclusion out of context. However, just read through that Bad Conclusion again and ask yourself...do you have any idea what it's talking about? Even though it will be in context, the Conclusion--for that matter, all sections--should be understandable, in some sense, on their own. Here in the Conclusion, you should begin by restating the purpose in order to remind your reader what it was.

First part of the next sentence. "It was very valid...." Let's ignore the fact that whatever "It" here refers to is unclear, because there are some deeper content issues here. Validity, unlike confidence, is not really something that can occur in degrees. Either results are valid or they are not; so to say they are "very valid" just sounds, well, like you don't know what validity means. This does not mean there are no gray areas; but the gray areas, where validity is concerned, essentially affect your certainty about the validity. The results could be valid; or there might be slight reason to suspect their validity; or the validity may be moderately suspect; or you may have only slight confidence in their validity; or they may be invalid.

The end of the previous sentence, and then the third sentence. Why "I?" No "I!" Setting that aside...you are "confident" in "accurate" results with -48.5% error? Really? Then you don't understand what -48.5% error means! Now to be honest, the majority of students don't write things like this; but when they do, I think it is out of some desire to make their paper sound better more than it is that they don't understand the issues. Honesty is paramount, however. These results are not good; they are certainly not accurate; and if you are going to make the astounding statement that you are confident in some bad results, you'd better be prepared to back it up with some strong justification. In this bad example, of course, no justification whatsoever is provided.

Next. While it is true that precision cannot really be assessed from one trial...if that's the case, why mention it at all?

Next; the bit about the experiment working "as we expected." Setting aside the "we," there is still the issue addressed previously--with the poor percent error, did this experiment really go as expected? Further, since we have already been given the unjustified opinion that the purpose was accomplished with great confidence and validity, this sentence's worst offense is that it is pure filler.

The last sentence. A very half-hearted attempt at justifying the astonishing (albeit vague) claims made earlier in the Conclusion. Sources of error are mentioned--but you should at least state one or two examples here, without going into detail; if for no other reason, then to provide a nice transition to the Discussion. Hopefully, it need not be said that clearly the end of the sentence is unthinking bravado. Obviously, sources of error mattered quite significantly if the percent error was almost 50%.

So let's see how we can improve upon this rather sorry affair.

GOOD CONCLUSION: The purpose of this experiment, to determine the specific heat of a sample of lead, was accomplished in that all the procedures were carried out with moderate success and a specific heat for the sample was calculated. However, given the low accuracy and rather significant percent error of -48.5%, there is not much confidence in these results, and their validity is highly suspect due to the near certainty that multiple significant sources of error occurred, most prominently a loss of heat to the surroundings during the experiment. The purpose of learning how to perform a calorimetric experiment and its accompanying calculations, however, was definitely accomplished, despite the less than impressive results, which clearly did not agree well with the expected value. Thus, while a moderate failure from the theoretical standpoint due to the errors that will be addressed in the Discussion, from an educational perspective at least, the experiment was a success.

For the most part, this much better version speaks for itself. I'll just point out a few things.

First, note that this Conclusion would transition well from the Results, and into the Discussion. The way that ideas are layered together inside and between sentences sews the whole thing together much better than does the sequence of short, poorly detailed sentences in the Bad example.

Second, note the use of multiple purposes. Since the primary experimental purpose was not accomplished all that well, having the secondary educational purpose allows for a claim of at least some success, while being completely honest about the primary purpose's failure.

Finally, it's not always necessary to remind your reader that you're going to talk about errors in the Discussion; but it can be a nice touch, especially if your errors are significant; because you do have to at least mention them here; but you are not going to go into detail about them here.

Wrapping Up the Conclusion

The Conclusion is perhaps the most oft-misunderstood section of the lab report. Maybe people find its name misleading--I don't know--all I know is that one of the most common problems I have seen through the years is students putting things in the Conclusion that don't belong there. The next most common problem is not putting things in the Conclusion that do belong there. There's an odd sort of shift that occurs with some people, in that things that should go in the Results end up in the Conclusion; and things that should go in the Conclusion end up in the Discussion.

So what is the Conclusion all about?

First and foremost, there *is* a conclusion that must be made in the Conclusion, as its name suggests. That conclusion is *not*, however, what your final outcome was. Your final outcome is a *result*, not a *conclusion*, and therefore it belongs in the Results. The conclusion that you must draw in the Conclusion is not to *state* your final outcome, but to *assess* your final outcome.

In other words, the big questions you should be answering here are: 1) Was your purpose accomplished, and 2) how well was it accomplished?

Now, in a very general sense, you should have already done this in the Results, where you should have stated how your outcome compared to expectations, and whether or not they were reliable. But here, you must very specifically and definitively state whether or to what degree the purpose was accomplished. Then, you must justify that statement.

This assessment of your experiment should *always* include a discussion of validity and confidence; and when possible, should also always include a discussion of precision and accuracy.

"Validity" here refers to whether or not the results are trustworthy due to known or suspected problems with the experiment. If you know something did not work properly and it impacted your results, they have little validity. If you suspect something was wrong, then the validity may be suspect. If there were no major problems besides unavoidable and minor sources of error, then your results should be valid. (Note: If there were no known major problems but your results were very poor, validity is an issue even if you are not certain of the cause.)

"Confidence" here refers to your level of certainty in your outcome, based on the outcome itself, the validity, and sources of error. Note that it is possible for results to be valid, but for you to have little or no confidence in them; but if results are invalid, you cannot really justify any significant confidence in them. Confidence should be assessed in degrees, ranging from high confidence to no confidence. Moderate confidence, or moderately low, moderately high, etc., can also be used as appropriate. Note that confidence has nothing to do with how you felt while performing the experiment, or how you feel about it after the fact. It has nothing to do with your feelings; it has to do with your certainty in your results.

Precision, as you know, refers to the closeness of measurements to each other; but it can also be used to refer to the number of significant figures in a result. For example, 2.500 g is a more precise measurement than 2.5 g assuming both were made properly. Either or both of these uses should be addressed when it makes sense to do so. Obviously, if you have no quantitative results, precision is not an issue--and it should therefore not be mentioned. Also, if you have not done multiple trials or measurements, precision is again not an issue--and should not be mentioned. If you feel it necessary, you can explain why you're not mentioning it.

Accuracy, as you know, refers to the closeness of measurements to the accepted value. Even if you have only one trial, accuracy can be assessed. Note that it is also somewhat assessed in the Results section as well, when you compare your outcome to the expected, for example with percent error. Even when you have no quantitative results, however, the basic issue of accuracy can be assessed with the idea of whether or not your results agreed with theory.

Your results' agreement with theory--or lack thereof--should be specifically addressed in your Conclusion by the time you finish it, whether it is involved in discussions of accuracy, precision, confidence, or validity, or if it stands alone.

The justification of your experiment's validity is primarily from sources of error--which should be alluded to in a general way only in the Conclusion, as you will elaborate on them in great detail in the Discussion. However, if you have not been able to identify any significant sources of error but your results are so questionable as to warrant dismissal, this is also a justification for a lack of validity. It is always best, though, to focus your justification for validity on sources of error.

The justification for your confidence is a bit more complex; and you have to take into account the validity (including sources of error) and the actual outcome (agreement with theory) to decide how confident you are--or are not. Remember again that your confidence has nothing to do with whether you "feel" confident; but with how much certainty you have in your outcome, based on how much certainty is justified.

Precision and accuracy don't need to be justified because they will be evident from looking at your results; though if you feel the need, you can clarify what your statements about precision and accuracy mean. Certainly, you can feel free to gauge levels of precision and accuracy by specifically looking at your results. (For example, you could say, "The results were very precise, since all trials fell within a range of 0.03 g/mL.")

One of the most important things is to avoid making wishy-washy statements. Your Conclusion needs to feel like a solid conclusion--even if that conclusion is that the experiment was a total failure. It's a bit trickier when the experiment has moderate success--but in those instances, you still need to make your statement definitive. For example, "The purpose was accomplished with moderate success" is a definitive statement; though you would certainly want to clarify it as much as possible, for example, "The experiment was moderately successful in that all the unknowns were identified with a fairly high degree of confidence, despite the fact that there were some discrepancies when the results were compared to the known properties of substances."

So in conclusion, here are my tips for writing the Conclusion.

1. Restate the purpose. This will help ensure that you...
2. Make a clear statement about whether the purpose was accomplished, by...
3. Assessing the validity, confidence, precision, and accuracy of your results...
4. All of which you justify with reference to the appropriate sources.

Good Discussion, Bad Discussion

The Discussion is another one of those sections that is too long for me to give whole good and bad examples; so what I will do is highlight the most common problems and give examples of small bits of good and bad Discussions.

The first place people often make an error is right at the very beginning. Yes, a lab report is broken into sections; yes each section has its own purpose; and yes, you even head each section separately. That does not mean that basic elements of writing, such as transitions, should be ignored. You certainly don't need an elaborate, flowery bit of writing--although the Discussion and the Introduction are two sections where you have a bit more leeway in that regard. However, it is nice to at least make a concession to the fact that you have a reader and provide at least a sentence or two acknowledging that you are connecting this section to the previous.

In other words, even though the first part of your Discussion is an analysis of errors, don't just start talking about that right off the bat. Provide some context.

BAD DISCUSSION: Basically the biggest source of error was a problem with the thermometer.

Ignoring the fact that the first word here is basically a terrible word to put at the beginning of a section (or a paragraph; probably even just a sentence), note that we have no context here. Of course, your reader has presumably read everything up to this point; however, this is a very jarring and unprofessional beginning to a Discussion.

GOOD DISCUSSION: Although the purpose of identifying an unknown metal by experimentally determining its heat capacity was accomplished with precise and accurate results, several known and possible sources of error are likely to have contributed to the observed deviation from the expected value. These potential errors, including known issues with the calibration of the thermometer and the unavoidable loss of heat to the surroundings, as well as a few other minor possible problems, certainly contributed to the (low) percent error of -3.5%; however none of them was significant enough to seriously impact confidence in the identification of the unknown.

In addition to the more sophisticated sentence structure and the elevated vocabulary as compared to the first, note that this second example really provides a segue from the Results, in which the data would have been processed and analyzed to arrive at the final outcome, and the Conclusion, in which the success of that outcome was assessed, into the upcoming explanation of sources of error that affect that outcome and your assessment of it.

Students will sometimes protest that they feel like they are being repetitive when writing lab reports, because they find themselves duplicating information in various sections (other than the Abstract, which is obviously designed to duplicate information). While I am glad that students are thinking about such things, and while I would say that it would always be better to avoid using identical phraseology in different sections so that it *sounds* repetitive, the truth is that you really *do* have to repeat yourself, at least a little, when writing a lab report. Except that it is repetition for a reason. One might call it *reiteration*. The difference between repetition and reiteration is one of purpose, and therefore style. Repetition itself can be somewhat mindless; but reiteration serves to remind your reader of important information. The trick to good reiteration is to repeat only what is necessary for your reader to remember at this point in your paper, and then to write it in a way that serves that purpose.

Note, therefore, that the GOOD example above certainly does repeat information that surely was addressed in previous sections; but look at what it is doing there. It is reminding the reader of the information in a sort of summarizing manner (without using the phrase, "to summarize," which would make it feel more like repetition) all leading into the rest of the Discussion.

The number one biggest problem area in the Discussion, however, is the error analysis itself. Most students do a fairly decent job of coming up with the most likely sources of error; although certainly, making sure you do that is absolutely critical! The most common problems students have in their analysis of errors are: 1) weak specificity; 2) inadequate evaluation.

"Weak specificity" refers to statements that are so vague and general as to be essentially useless. Weak specificity answers the question, "What were the potential problems with the experiment?" with the answer, "Things could have gone wrong." True. And useless. Following are some examples of weakly specific statements.

BAD DISCUSSION: a) The sample could have been contaminated, which would throw off the results. b) The measurements may have been off, which would throw off the results. c) The beaker was heated too quickly, which threw off the reaction. d) The timing measurements were inconsistent, which threw off the calculations.

Each of those sentences could probably be found, verbatim, in more than one lab report I have read through the years. Each of those sentences makes me *cringe*. If I never again in my life read about how an experiment could be "thrown off" by some nebulous problem, it will be far, far too soon.

So how do you make more specific statements? Witness...

GOOD DISCUSSION: a) If contamination was present, it could have seriously impacted the results, depending on the type of contaminant. An acidic contaminant, for instance, would have made the unknown, which was an acid, appear more concentrated than it actually was. A basic contaminant, on the other hand, would have made the unknown appear less concentrated, since the contaminant would have reacted partially with the unknown before the standard was added. b) Some problems were suspected with the measurements; the masses, in particular, were likely a bit discrepant, considering the problems noted with the balance that was used. Although the masses likely deviated by only +/- 0.05 g from their actual values, this would still impact the results. If the measured mass were lower than the true mass, the calculated density is too low; while if the measured mass exceeds the true mass, the density reported is too high. c) The beaker containing the reaction mixture was heated faster than recommended (reaching boiling in about 5 minutes instead of the prescribed 15 minutes). While it is obvious that the reaction still occurred since the desired product was obtained, the rapid heating may account, in part, for the low percent yield. The two problems that could have occurred due to rapid heating were poor formation of product due to the fact that the reaction was not given the recommended time to complete, and side reactions occurring at an increased rate, using up one or both of the reactants more rapidly in processes that did not lead to the desired product. d) Since the timing errors were mostly due to human reaction time, which is about 0.2 to 0.3 s, and the times in the trials were all about one second, the uncertainty in each time measurement is actually a sizable fraction of the measurement itself. This means that each trial's velocity as calculated from the experimental data could actually vary as much as 30% from the actual values in either direction, depending on whether the recorded time was too short (producing higher velocities) or too long (producing lower velocities).

Note the difference in specificity; and note that what a lot of it comes down to is *detail*. However, that does not simply mean, as many students seem to think, that longer is necessarily better. The issue here is that the first statements were so vague as to be useless. In the "Good" examples here, though, the specific effects of each potential source of error are explained and elaborated.

I will now continue, rather than with more "Bad" examples, of which the ones I have already provided demonstrate all the most likely problems, with the next part of the "Good" Discussion for each of the four cases. In these portions, I will focus on the evaluation aspect for each source of error.

GOOD DISCUSSION: a) It is unknown whether or not a contaminant was present. Certainly, no known contamination occurred, but that does not preclude the possibility that it did. Given that the results were all slightly higher than expected, it is possible that an acidic contaminant was present, and very unlikely that there was a basic contaminant. The deviations from the expected values are not large, however, and there are other possible explanations for them--such as the concentration of the standard solution being lower than expected either due to a problem with the stock solution or unintended dilution if the buret was not completely cleared of water prior to filling it with the standard. If contamination did occur, therefore, its effect would appear to be relatively minor. b) The problem with the balance was not identified till after the experiment was finished, so retrials with a better balance could not be performed. However, subsequent analysis of the balance showed that the masses it generated were probably relatively accurate, albeit not precise. Thus it is a certainty that the calculated densities from the trials are not reliable past the tenth of a gram; however, given the performance of the balance and the nature of the calculations, the densities are likely to be very accurate *in* the tenths place, with a likely variation of +/-0.01 to +/-0.02 g/mL. Thus, while the error in the masses reduces the precision of the results below the desired levels, the basic accuracy is not seriously affected. c) Given the low percent yield, the knowledge that the substances in this experiment are known to undergo a few side reactions, and the darker than expected color at the end of the reaction, it seems relatively certain that the rapid heating caused in increase in the rate of one or more of those side reactions, thereby reducing the amount of reactant available to form the desired product. It seems less likely that the problem with the heating was due to poor product formation, since increasing the temperature generally increases reaction rates for all reactions present. Of course, while the increased presence of side products is highly probable, other factors, such as product loss during transfer and purification, almost certainly contributed to the low yield as well; especially given that while there was evidence of side products, like the desired product, they did not appear to be present in large quantities. d) Using the prescribed equipment and techniques, and given the conditions of each trial, the relatively large timing error was unavoidable. However, if the timing error was random, the full set of data should still give a range of velocity values in which a fair amount of confidence can be placed--if not in precision, then at least in a degree of accuracy. The fact that all the times were relatively close together, however, indicates at least the possibility that the error was systemic rather than random. If that is the case, then all the velocities are either too high or too low, depending, of course, on the direction of the systemic timing error. It is unknown whether the error was truly random or systemic. If they were systemic, it would seem likelier that the times were too long, meaning the velocities would be lower than the true values. Again, however, in the worst case scenario the error range should not be more than +/- 30%, which while far larger than desirable, does at least give a general idea of the velocities.

Note, again, that what this comes down to is *detail*. And again, this does not mean throw everything up to and including the kitchen sink into your Discussion, which some people seem to think is the right approach. "Long" isn't a requirement of the Discussion, but "detailed" is; and though the latter generally implies the former, just because it is the former does not guarantee it is the latter.

I would also point out that, if you put the pieces together from the two sections of "Good Discussions," each source of error should have several detailed, elaborate sentences that address it--at minimum. In more complex labs (Chem II and occasionally Physics), more complex sources of error may take a whole paragraph just for that one error.

Last, but not least, is the end of the Discussion. Remember, this is your last hurrah; your last chance to impress your reader. This is why you want to talk about why the experiment they have just read is important--whether in the grand scheme of things, in the class you are taking, or life in general, or all three. Note: you don't *have* to have all three! Please...*please*...if you can't think of how to apply it to life in general, or if the application is really flimsy, then just don't even try. And if you're not going to try, then just don't mention it. Just imagine, for a moment, what your reader will think when he or she reads, "This experiment doesn't really apply to everyday life." Even if you follow that up with a great application to the broader scope of science or the course, you have just told your reader, if only for a moment, that this wasn't an important thing to read. Not a good idea. You should always...and I do mean ALWAYS...be able to apply the experiment to a broader context of the subject, or to the class.

And note, that by "the class," I don't mean your grade.

Again, look at it from your reader's perspective--your reader as in your audience, not me, your teacher. Frankly, your reader won't care if doing this experiment will help your grade, or help you to pass the class, which you need to graduate. (And yes, I have read all of these "reasons" for the importance of an experiment in actual student lab reports.) Your hypothetical audience doesn't know you or care about whether you pass your class. They want to read about your work. Period.

So when I say to apply it to the class, I mean what you're learning in class. For example:

GOOD DISCUSSION: This experiment was valuable not just in that it provided the opportunity to practice the common analytical technique of titration, but in that it helped improve understanding of acid-base neutralization reactions and indicators.

Honestly, in a "real world" setting you wouldn't be writing about a class, which you wouldn't be taking; but it still could be important simply because it *does* improve your and your readers' understanding of whatever it is you are studying.

Finally, your reader (and I include myself here) doesn't really care about your feelings about the experiment. They are totally irrelevant to the work; and they are totally inappropriate to include in a lab report. Lab reports are not reflections. Lab reports are not personal journals. They are formal presentations of scientific work.

This is not to say that you cannot express a professional sort of pleasure at a successful endeavor--that is certainly appropriate. On occasion, if your results are truly noteworthy, you might even express a bit of excitement, in some appropriate manner. And while you are certainly welcome to opine on problems with the experiment, or ways in which it could be improved, it is never appropriate--and it is wholly unacceptable--to talk about "not liking" an experiment. Whether you liked it or not is irrelevant to the report you are writing. Even expressing like is a bit unprofessional, but it can be passed off as enthusiasm, and is sometimes excusable. Expressing dislike, however, just makes you look very, very bad. And that is definitely not a wise thing to do in the last part of the paper your reader--and your grader--will read. This is why, remember, you should always end your Discussion on a positive note.

Finally, remember that while the Discussion is the last thing your reader will read, it is not the last thing you will write! So one last little suggestion would be that after you write your Abstract, even if you don't go back and proofread the whole report (which you should), you probably ought to at least go back and read your last paragraph of the Discussion. Because remember: the last thing you write will make your first impression; but the Discussion will make your last impression.