Guide to Undergraduate Research

Darrell W. Guillaume
Department of Mechanical Engineering

Crist S. Khachikian
Department of Civil Engineering

California State University Los Angeles

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Chapter 1 -– Introduction

What is Research?

Research is an exciting endeavor. It is a systematic adventure pursued to understand the natural or social worlds. Through research, we explore phenomena to discover or interpret entities such as behaviors, natural phenomena, and theories. The adventure is an investigation that begins with a question and usually involves learning, planning, designing, constructing, testing, analyzing, and evaluating. It typically utilizes information repositories and tools such as libraries and internet archives, basic and applied science and technology, and modern instrumentation. Most scientific research begins with a hypothesis, a tentative explanation to be tested through further exploration. The hypothesis can be formed from a researcher's current knowledge, but it is most often based on thorough knowledge of the literature in the field of study. Once the hypothesis is established, an experimental plan is developed. To implement the plan, equipment and facilities need to be located and a schedule needs to be created. If the equipment does not exist, the researcher often must design and, occasionally, construct it. Research projects can last just a few hours or many years. The results are typically shared with the scientific community though organized presentations at conferences or in technical journal publications. The bottom line is that researchers systematically pursue questions about the world to discover things that no one else has ever discovered before.

What is Undergraduate Research?

Simply put, undergraduate research is research performed by an undergraduate student, typically at a university or college. A research laboratory is much like a small company. Faculty members are granted laboratory space at the university as part of their professional responsibilities. Other than space and utilities (overhead costs), the professor must often fund the lab with external research grants that come from sources such as NASA or the Department of Defense (DOD). The professor who "owns" the lab is analogous to the CEO. Typically, the professor has a few doctoral (Ph.D.) students who are doing the most theoretical (cutting edge) research. These doctoral students directly report to the professor. In many labs, the professor also hires masters (M.S.) students to work alongside the doctoral students. There are typically two or three masters students for every doctoral. student. To help the masters students, the professor often hires undergraduate students. Although the undergraduate students perform less theoretical research than the graduate students, they fill a very important role in the lab. The undergraduates typically receive some compensation for their work, whether it is credit for courses such as independent research, monetary pay, or both. Compensation is determined by the professor’s budget, stipulations in the funding grants.

How Will it Help?

Undergraduate research can foster interest in the subject, increase learning, encourage group study, provide a semi-private place to study, and help form bonds with faculty. It also can provide an edge after graduation.

Fosters Interest

Curiosity and interesting problems fuel human learning and interest. As you struggle with a part of a research project and find that you are lacking in knowledge in a field, you will be motivated to learn more. Research is much like a game or puzzle. You win when you are the one to first find an answer or solution to some problem that others are also trying to solve. Good games are interesting; they hold our attention and challenge us to use our knowledge, creativity, and luck to beat the opponent or achieve some goal. Undergraduate researchers who compete with students in laboratories at other universities on similar problems are highly motivated and much more interested in their subject than students whose only way of learning is in the classroom.

Increases Learning

Research in your field of study will increase your learning and retention because you will be applying the material presented in the classroom to actual real world problems in the laboratory. This is precisely why required labs are often found in program curricula. When you ask former students what they remember from classes at school, most mention an experiment or hands-on project that was assigned. This is because these hands-on activities are more interactive and can create an understanding that lectures, or reading, or working from a book cannot provide alone. Many students will recall that the project of their memories did not go smoothly. Problems and challenges increase the memory of the experience…and learning as well. The greater the number of ways that a student is exposed to a topic (i.e. audible, visual, tactile), and the harder and longer students are required to work at a problem to solve it, the deeper the resulting understanding and the longer memory of the information. Thus, performing research is an excellent means of obtaining hands-on learning at the university level and gain a deeper understanding of the material presented in your courses. You will be able to use that deeper understanding of the subject to help you learn related topics. New knowledge is often fragile. Application and utilization will fill in holes in your understanding of new topics and solidify understanding. Further, laboratory work enhances learning because it presents tasks that closely parallel those that you might find in your post-college work world. It demands you to develop the varied knowledge, skills and attitudes (such as persistence) that will help you succeed later.

Encourages Group Study

As an undergraduate researcher in a lab, you will have close contact with other students, both undergraduate and graduate, and the professor who runs the lab. There will be social occasions (lunches, parties) along with the work. Through these interactions you will likely develop close friendships. You will find yourself taking similar classes as your lab mates and will receive assistance or assist others on course material. Sometimes you will have completed the course before your lab mates, sometimes they will have completed the course first, and sometimes you will be in the course together. Through this group study, you will learn the material faster (not spending hours on a problem finding a simple mistake later). When you need to teach a fellow lab mate a difficult topic, you learn the material more deeply. The masters and doctoral students will be an invaluable source of additional help. The graduate students have learned the material both in the classroom and in practical applications in the lab and will probably be quite willing to clarify concepts and help with problem solving. Professors spend a great deal of their time watching over their research projects and are usually quite willing to help students with conceptual questions or homework problems. Not only do professors care about the students who work with them, they know that the more their researchers learn, the better they will be at their assigned tasks.

Provides a Semi-Private Place to Study

Although the primary purpose of the lab is to conduct research, it will also provide a place for you to study and do other non-lab related activities. Typically students who work in a lab are assigned a workspace (usually a desk) to do their research during their assigned laboratory hours. When they are not on duty, they can use that space as they see fit. Most professors allow students to study there, take care of personal business (pay bills, deal with academic paperwork), or sleep (which is a much needed commodity). Your desk will be in a locked room that only lab personnel will have keys and typically it will have drawers for your personal belongings. Since most professors want their researchers to work long hours in a comfortable environment, a microwave oven, refrigerator, and coffee maker are typical equipment in university research laboratories. Thus, a lab often gives undergraduate students a home base that can allow them to save time and address their many responsibilities.

Helps Form Bonds with Faculty

As a researcher, you will work more closely with a faculty member than is possible if you choose the "only course work" path. You will get to know your professor as a real person, as a person with a great deal of knowledge, and as a person with faults. You will learn about the professor's likes and dislikes, idiosyncrasies, and personal life. Likewise, the faculty member will learn about you in great detail. The professor too will get to know you as more than a student in a seat in a classroom. The faculty member will know your strengths and weaknesses and will work with you for self improvement. Your professor will be your mentor who can help you with academic and career decisions. Academically, the professor can provide guidance in the selection of elective courses and can help you understand the university and department procedures necessary to get things accomplished. Your faculty member will also be able to provide input on job offers (both salary and benefits) and graduate school decisions. Letters of recommendation are required to succeed in both the worlds of work and further study. A faculty member who has come to know you as a person and has seen you perform both in a classroom and in a laboratory has the ability to write a much stronger letter than one who only knows you as a grade for one course in a particular term of the academic year.

Provides an Edge After Graduation

After graduation, students typically compete for positions in companies, in government agencies, or for graduate school admission. You will find that there are many qualified people in the world, and that the way to get hired is to make yourself stand out. Research experience on a resume can help you stand out. Although your research experience does not have to be related to the field you are trying to enter, it does help. A broad range of research positions can even provide more of an edge, but not so much that you are scattering from place to place. People who are considering hiring or admitting you want to see that you know what you are getting yourself into and that you know how to work with people to accomplish a common goal. Potential employers and graduate school personnel know that students with research experience have developed competence in tackling ill-formed problems, in working with others, and in carrying through with important projects. Research experience on your resume, they know, will increase the likelihood of your success in the field.

Chapter 3 - Finding a Mentor

Time and Willingness

It may sound obvious, but a professor has to be willing to share knowledge and time in order to be a mentor. In general, professors enjoy working with students and sharing what they know, but they are very busy people. Depending on university expectations, faculty are expected to teach, work on university committees, perform research, write grant applications, and publish. Therefore, there is always a limit to the number of students any one faculty member has time to mentor no matter how willing they are to work with students. In fact, some faculty are too busy and are unwilling to be mentor. The best way to learn which faculty are willing to be mentors is to ask fellow students what they know about the faculty in your college, ask faculty for their opinion during advising sessions, and ask the department staff (secretaries and technicians). Because staff members work with faculty in a variety of ways and see them interacting with others, they may be in a unique position to give insights into which faculty may best match your mentoring needs.

Ability to Communicate

Being able to communicate with your mentor is absolutely necessary. Many people have vast experience in the field and knowledge unique to their subject but lack the skills to communicate it. Each area of study has its special language, filled with words designed to promote clarity among experts in the field. A good mentor has to be able to take expertise in the field and explain it clearly. The mentor needs to be able to communicate ideas in common language while simultaneously helping the student develop specialized vocabulary, or the language of the field. The mentor needs to be able to word concepts in multiple ways until the student grasps ideas. In a way, mentors are translators who speak with students in one language as they help the students master another. Clear communication can take a great deal of time, effort, and patience because concepts and terms that are very clear to the mentor or other experts may be very new to the student. What tips do you have for me to find a good communicator? Maybe…In selecting a potential mentor, think about which of your professors had skills to make difficult concepts clear. Ask around. Which faculty have the reputation for communicating well? Are there plaques naming teaching awards hanging in the department office? Good teachers are usually effective communicators.

Successful in the Field

If you know the exact field that you want to study, you need to seek out a mentor who is successful in that precise area. Professors each have their own specialization within their general field. They may have a very broad background in many other fields but that is not enough to be a mentor. Although professors teach particular classes, they may not be experts with a record of success in the topic. It may mean no more than the professor knows more about the course subject than the students know. A clearer measure of a mentor's success in the field can be found on the curriculum vitae or on a list of publications. Often, this information is available on a faculty webpage. Use the topics of the publications as your guide, checking the fields of the majority of your potential mentor's publications. Faculty may publish a few papers outside their areas of expertise, but the majority of publications will be in the area where they are most successful and have the greatest professional knowledge. If you do have access to the professor's curriculum vitae, look to see if he/she does any consulting or if he/she worked outside of academia before becoming a professor. The field that the faculty consults in or where he/she worked in the past can also be an indication of where the professor has been successful.

Willing to Advocate

A good mentor will fight for you. Select a your mentor who will advocate for your best interests whether you are present or not. Ideally, an effective mentor will nominate you for scholarships and awards and then support your nomination in front of committees, department and college meetings, and other faculty. Often, the student who earns many university and professional awards is simply the mentee of a faculty member who spoke up at the right time during a department or college meeting. Further, your mentor should be there during your technical presentations to help with last minute questions and to support you if you get into trouble during the question-and-answer period. When notified of an internship or professional position, you should expect your mentor to notify you about it, give advice on how to apply, contact people who might help you get the position, and support you when contacted as a reference. Clearly the role of advocate requires much of your faculty member. To earn this kind of advocacy you will, of course, need to prove yourself competent and reliable at every opportunity.

Attitudes and Skills for Mentoring

As a student, you need to be able to identify the attitudes and skills in a professor that are necessary to be a good mentor and of value to you personally. Not all professors will have all of these skills; some may be strong in some areas and weaker in others. As a student, you may decide that you do not need a mentor who is strong in all of them, but it never hurts to have someone who is. Before selecting your mentor, determine which attitudes and skills are most important to you, and then look for a fit. There are basically two ways to determine if a faculty member has mentoring skills. The first is to ask around. Keep your eyes open and observe faculty in action with other students. The second is to get to know faculty during class, during office hours, or during university social occasions.

Three attitudes and skills valued by mentees in the teaching profession (Rudney & Guillaume, 2003) include faith, feedback, and freedom. They have applicability for engineering mentees as well.

Faith

Your mentor must have faith in your capacity to succeed. Your mentor must believe in your current talent and abilities as well as in your potential to develop additional skills via mentoring and further study. . Your mentor must trust in your ability to tackle difficult problems. Your mentor's view of you as a competent person will drive the feedback and support you require. Although your mentor may see you as a diamond in the rough, it is essential that your mentor believe that—even if much growth is required—you are on your way to success.

Feedback

Your mentor must be able to provide positive feedback when you do well and properly directed criticism when you are on the wrong path. The mentor will work with you to set up a clear time line for completion of research tasks and your degree program. The mentor will help you set high but attainable goals. It is very important to that the mentor selects projects that have a good chance of success. Small projects should be assigned at first with the level of difficulty and challenge increasing as you grow in competence and confidence. Your faculty member should clearly define your responsibilities and include regular feedback and evaluation on at least a weekly basis at a scheduled time.

Freedom

You will need the freedom to both succeed and fail, because both successes and mistakes encourage learning and growth. Too much guidance and too much control over time frames and project issues is not good mentoring. The tasks may get completed, but you will not grow or learn. A good mentor will know how to provide just enough support so that you are free from an overabundance of advice and that you will avoid costly and time-consuming mistakes. When you approach a mentor for help, he/she should not directly give you the answer but give you guidance for you to discover the answer yourself. In a way, a skilled mentor provides freedom…with a safety net. A skilled mentor provides opportunities for you to try your own plans but knows when assistance is necessary.

Role Model

Research on mentoring suggests that many mentees view their mentors as role models, as people they would like to emulate. Can you picture yourself doing your mentor's job in the future? The mentor should be someone that you respect. It is often best if the mentor has a similar belief system and a similar definition of success. A good mentor is a role model through both words and actions. The mentor should be willing to open up to students and provide a personal window for you to see the mentor's ethical, scientific, and professional behavior and attitude towards work. The mentor needs to be able to communicate feelings about the profession by sharing both the joys and frustrations that are part of any job. The mentor should share both successes and failures with the students and explain what they mean, both professionally and personally. You probably only understand a part of what a professor does…most probably the professor's scientific work. A good mentor will take the time to raise other personal topics for discussion with the students. The professor should be willing to share what a typical day and week is like for a faculty member. It really will help you understand your mentor if you know about family obligations or the challenge of a dual-career partnership, and the challenge of balancing the professional and personal aspects of life.

Chapter 4 - Reading Scientific Papers

What is a Scientific Paper?

Scientific papers are the primary literature of science. They report the basic results and observations of science and the first theories, ideas and conclusions that are based on them. They are usually the first place that new science is published.

Peer Review Process

Although most papers are published in journals produced by commercial publishers, the scientific quality control is usually undertaken by scientists who are not paid for this work. When a paper is submitted for publication, the editor sends it to two or three of these referees who examine it and may recommend its immediate publication or rejection. More often, referees will make suggestions about how the paper might be improved.

Because a paper has been published in a peer-reviewed journal does not mean it will always be right but it does mean that it is plausible. The most egregious errors and foolishness will have been removed. Readers can place more reliance on papers that are published in peer-reviewed journals and authors can feel that their work has been given some mark of approval if it has been so published.

Peer review is not a perfect system. You might care to jot down a few problems that may arise from the situation either from the viewpoint of a referee or an author. Despite these problems it is still the best system so far identified for this purpose.

Selecting a Paper to Read

First, you need to choose a topic. If are joining a research project in progress or a lab group, there are probably some classic papers that you should read. Ask your advisor or peers in the lab for these papers. These papers, along with others you find, are meant to help you acquire background knowledge. Some good sources of background knowledge are *Science, Nature, National Wildlife, American Scientist, Natural*

History, Discover, Scientific American. You can find papers in specialized review journals as well as in scientific journals. Books are also a good source to get a short description of the topic you are going to work on. People will often page through two or three of their favorite journals just to look for interesting articles and to generally keep up with what is going on in science. Most libraries have designated sections where they display recently received journals. NEVER take the findings presented in a newspaper article at face value! Always look up the citation and see what it says for yourself. See if they got the message right. See how strong the evidence is. Certain papers such as the New York Times are much more likely to get the facts straight.

Keep master list of references

Reading a Scientific Paper

There are many approaches to reading scientific articles. A scientific paper cannot be read in the same way in which a novel or other form of literary entertainment is read. Although this may seem very obvious to you, many people simply read a scientific article from front to back once and feel that they have thoroughly read what was to be read. However, a scientific article demands that you analyze what is being said at many important points before you proceed. This makes the reading of science slower, and for some people more tedious.

Reading a scientific paper must be an active process with a continual engagement on the part of the reader. Papers are almost a type of code with a great deal of information packed into a limited number of characters. Superficial reading is rarely any used, so how do you read a paper?

This is not a prescription but is one way of reading a scientific paper. You will find a method that suits you. You might like to start finding your personal style in this by following the method below and identifying any problems it has for you.

Phase I: Screening the Article

Read the title slowly and look for key words. Make sure the title makes sense to you. Look through the authors to see if there is anyone whose name you recognize, whose work you know. This is an important process in trying to judge the quality of the data. Look at the date. There is a lag period between when the research gets done, when the article gets written and when it gets published. In addition to the publication date, many journals list the date when the article was received, and the date when the article was accepted. Interestingly, journals that are refereed (see below) are more likely to be delayed in their publication, but are less likely to contain inaccurate or frivolous articles.

Some articles have a brief list of key words. Although they are sometimes misleading, they are usually quite informative and should be looked at early on.

Phase II: Getting the Point

Read the abstract looking for key words. Read it slowly until it makes sense. Read the Introduction. The introduction is often the easiest part of an article to read. In some cases, it is also the most informative - not so much in terms of presenting new information, but in consolidating background information. Some authors will also present the point of their research in a way that is easier to understand than the way it is presented in the abstract. The introduction will often cite many of the references. This is an excellent time to begin looking at them. The references are particularly informative if they contain the titles of the articles being cited. You will want to go back to the reference page over and over again.

Phase III: Understanding the Approach

Peruse the figures and tables. You will not understand them this first time through but this will help you know what to look for when you actually read the article. Go to the discussion. Read the first few paragraphs and the last few paragraphs. If it is short and/or easy to understand, read the whole thing.

Phase IV: First Reading

If you get this far you may wish to photocopy the article if you have not already done so. Make sure the reference for the article appears on the front page of the photocopy; if not, write it in. The monetary investment will surely be trivial in comparison to the investment of your time. Skim the abstract and the introduction once again. At this point you should be able to have an adequate understanding of them. Skim the methods section. Ask yourself; are they repeatable? is there any new technique or idea? are there enough samples, controls, replicates, etc to make this a worthy piece of work? The methods section will need to be studied carefully only if you intend to use some of the procedures in your research. The methods should be studied carefully only in so far as they contribute to the understanding of the rest of article. Read the results section. Read the discussion. Study the figures and tables.

Phase V: Increasing Understanding

Reread the article in its entirety. You may wish to read several times. Be sure to write on the article. Circle words you do not know. Check important points. Question things you do not understand or that do not appear to make sense. X-off things that are wrong. Jot down ideas. Consult the references. Look up points that were not fully explained. Consult textbook to clarify general points. Look up words that are unfamiliar. Before leaving the article, reread the abstract once again. Don't get too frustrated, and don't give up! As you read, write down important points and lingering questions. Once you feel you have a pretty good grasp of the paper, summarize it. Your summary will help you talk to others about the paper and will help you if you have to read the paper again a week, two months, or four years later.

You should be prepared to do some work in order to acquire sufficient background for adequate understanding of an article. This will include:

1. looking up points made in the references
2. looking things up in textbooks
3. looking up words in dictionaries (particularly biological and medical dictionaries)
4. asking questions of people who may know

In general, people do not try to conquer every article they encounter. There are simply too many articles and it would require too much work. They tend to go through a sequential process of studying the article - all the while deciding whether or not to give it further attention. The decision is based on whether the article is of sufficient interest, relevant to your work, of general importance, of high quality and or accurate clearly written and accessible at least after reasonable amount of effort, "meaty", short!

If the paper is understandable and well-written, ask yourself:

1. What makes the paper easy to read? [Easy is relative.]
2. How detailed is the paper?
3. What questions remain unanswered?
4. How did the author link his/her work to previous research?
5. What does the paper contribute to the field?

Your answers to these questions will help you write lab reports that are supposed to read like scientific papers. If you find yourself cursing the author, ask yourself what makes the paper so impenetrable or otherwise maddening. An understanding of bad scientific writing will also help you write lab reports that are supposed to read like scientific papers.

Try reading difficult articles with other students. You might move more slowly through the article, but when you reach the end, you might find that you more thoroughly understand the article than you would have otherwise.

Taking Notes

Taking notes is time-consuming; however, in the long run, it will help you remember the contents of the article much more clearly and quickly. What I usually do is write on the paper as I'm reading (underline, notes, calculations, etc.). After I'm done with the paper, I'll spend 10 minutes summarizing it. The summary can follow the same format as the paper (i.e., with section titles, *Introduction*, *Materials & Methods*, etc.).

Take care summarizing the methods section. Start with identifying subjects of study and then the procedure. Cite similar procedures (if you know them), and then describe theirs. Include justifications (they increased... to minimize...). If applicable, include study sites and sketch diagrams. Specifically, look for experimental design issues including use of controls, analysis methods, and sampling techniques.

In summarizing the discussion section, ask yourself the following questions: Do data support conclusions? If so, how? What was author's major contribution to study? What can be done next? (What questions remain for future research?) Can this paper be used in your own work? How?

Chapter 6 - The Laboratory Notebook

Introduction

Science is recorded in the laboratory notebook. The quality of any work is only as good as the recorded observations. A lab notebook is one of a scientist's most valuable tools. It is an essential part of "doing good science". The notebook must be **clear**, **concise**, and **complete**. The properly kept notebook contains unambiguous statements of "the truth" as observed by the scientist. Experiments that fail must be recorded as faithfully as those those that succeed. The student should realize that good note keeping is an acquired skill that can be of tremendous benefit in any career. However, writing good notes requires discipline and practice. A good research notebook reports things as they happen, not as they are recalled. It also reports what you are *thinking* in addition to what you are *doing*. This means writing out an easy-to-read summary of your ideas, why you are planning a particular experiment, what materials and processes you will use, and what you hope to find out. State your ideas clearly enough that someone can pick up your notebook years later and understand what you were thinking as well as doing on a particular date. An articulate notebook also helps to maintain workplace continuity when a long-term project is passed from one laboratory assistant to another.

General Considerations

Plain language

The point of a laboratory notebook is that it should say exactly what was done, and when, make clear who did it, enable someone else to do the same thing, and be durable and verifiable. Plain language is the best. Use the active voice (i.e., "I saw the solution change color in 10 minutes.")

Hardware

Laboratory notebooks should be hardback bound notebooks – you can stick/paste worksheets in where needed. Writing must be done in ink. Black ballpoint pen is best; fountain pen inks are not as durable as ballpoint pens and blue ink fades more readily than black. *Pencil should not be used for anything*. Also, never make notes on loose sheets of paper while promising yourself that "I'll copy it or paste it in the notebook later." You will always forget something or the details of something and will never be able to recall it in the future. Always keep your lab notebook with you while in the lab or in the office. This way, you can constantly write down thoughts, ideas, observations, et cetera.

Organizing Your Notebook

Basics

They key is to be **flexible** while adhering to some general guidelines. Each experiment needs a system that is right for it. The main thing to keep in mind is that you are practically writing for someone else. If the writing is clear to them, then it certainly will be to you. Achieving this requires some organization as well as a certain style. The beginning pages of the notebook should be devoted to the following sections (in order):

- Title Page: Give a page to state your name, address and an indication of the notebook's purpose.
- Table of Contents: Give 2–5 pages to the Contents so that you can find experiments easily.
- Table of Abbreviations: If you abbreviations, give a table to explain them.

Then, you should, number the pages. This is essential and should be done when the notebook is new.

Sections in Notebook

Each experiment (or section) in the notebook should be divided into subsections. Label the subsections according to the titles below. If an experiment runs for more than one day, you do not need to start the labeling process each day. Continue with the original framework until the experiment is completed or terminated. However, start each day on a new sheet of paper and label the section appropriately (i.e., on 27 Feb 2001, you might write "Observations and Data (cont'd from 26 Feb 2001)").

INTRODUCTION

The introduction to your experimental report should have the following: the title of the experiment (write this title on all foreign sheets pasted in notebook, e.g., print outs, copies from manuals/procedures, etc.), a statement of the problem (short), the date (2 July 2000 not 2/7/2000). Then, write the purpose of the experiment (a clear statement of the experiment). Following this, provide explanation and support of the proposed work: why is the experiment being undertaken? Why was the current experiment chosen? Cite the literature (if necessary). Show the relevant chemical reactions and other calculations that were needed to plan the experiment. What will be the benefits if the experiment "works"? The length of the introduction may be as brief as a single sentence or a paragraph. The Introduction should be a general look backward at what has been done and the reason for undertaking the current problem. Some of this material may be included in the Experimental Plan (see below).

EXPERIMENTAL PLAN

A description of the planned experiment should follow the introductory section. This is the part of the account that tells what you are going to do. Include your experimental hypothesis here. If you have detailed instructions already, paste them into the notebook. Use simple, direct statements or a bulleted or numbered list of instructions; look forward to what you intend to do - do not repeat the introduction. You can clarify your planned procedure by drawing a flowchart, outline, or numbered list of the experimental steps. Include notes on safety in this section, along with the properties of the materials that will be used and precautions for the various operations to be performed. A table of the properties of the materials you plan to use may be helpful. Such a table may include chemical formula, molecular weight, density, boiling point, melting point et cetera. Sketch the figures or tables you are going to get out of the experiments that will show the relationship you are trying to show with the experiments.

OBSERVATIONS AND DATA

This section might be considered the heart of your note writing because, in it, you actually record the observations that you make during the course of an experiment. You must objectively, honestly, and completely record your observations. The data you record will lead to the acceptance or rejection of your hypothesis, and will decide what future experiments may be done. The observations and data are therefore central to the whole exercise. They need to be:

1. Recorded honestly; the raw data is precious.
2. Recorded as you go, in ink, immediately. Do not trust your memory, even for a minute or so - someone talks to you, and that data is lost. Also, you don't want your mind occupied with trivial things and small details. You need to keep the overall plan in mind.
3. Do not use odd scraps of paper or the edge of your lab coat to record data
4. The data must be recorded completely. Don't worry too much about interpreting the data as you go along, and don't worry if some of the observations appear incorrect. Interpret only when you have time or know how to interpret.
5. Use good penmanship. Take care with numbers - never over-write, always cross out erroneous material with a single line and re-write the correct data.
6. NEVER use white-out.

This section can be a narrative description, a story, telling what you did and what you saw. If someone else did the work, be sure that point is obvious. If you are recording data that requires some calculation followed by plotting, set up your data table so that the X- and Y- coordinates will be in the columns and rows. This arrangement will make the plotting easier with less chance transposing numbers. Don't be embarrassed to describe what you think is a sloppy or poor technique. Your results hinge on what you actually do, not on how nicely you tell everyone it was done.

Format: spread your work out. Tables must be written in vertical columns, each column headed with the **quantity** and the **appropriate units**. Drawings should be large enough to allow labeling and should be simple and to the point.

Graphs: each graph should have the experimental title and the date written clearly. The axes must be labeled with the quantity and its unit. Include error bars if you know the error limits. Give a clear table of the data you used to plot the graph. If you print this graph using a computer, paste it in the notebook. You may leave space in the notebook for a graph, however, if you forget to paste it later or change your mind, you should cross out the space and write a short explanation on the side. Remember to define the plotting symbols. Generally, you don't want more than 3 or 4 curves on the same graph. For these curves, use different types of lines (i.e., dashed, colored, etc.). Note on or near the graph where the data that were used to plot the points can be found (i.e., notebook name, page, experiment title, etc.).

How much detail should be recorded in your notes? Could another student who is competent in your field pick up your notebook and repeat your work solely from the written description without additional explanation? If the answer is "yes", then you are doing a good job.

Important: *If the analysis is done on a computer, clearly indicate where you can find it later (i.e., red floppy labeled, "Sorption Experiment, 27 Feb 2001" stored at home, or on the hard-drive in "C:\MyFiles\Experiments\ Sorption Experiment\Raw Data.xls"). The more details you include, the better. Also,* ***backup data regularly*** *(weekly).*

DISCUSSION AND CONCLUSIONS

This section provides you with the opportunity to reflect on what you did and what you saw during the course of the experiment. This section can contain calculations, graphs, rearranged or interpreted data, and ramblings. Write this section after the observations are completed. Write any calculations out clearly, showing all the steps and using units throughout. Relate your results to your hypothesis - do they support or refute it? Comparisons must be as quantitative as possible. Record any ideas you have however brief - if you don't write them down, you'll forget them. Your conclusions should state what you found out; whether the hypothesis was supported or not; the error limits on your answer(s); a quantitative assessment of error should be made if possible; suggestions for improvement in experimental design; the error analysis will be useful here; what to do next. It is a section where you truly "think in the notebook". Do not use the discussion section to "simply restate the data". Use instead to "understand" the data. If the data clearly fit your hypothesis, then say so. If the two are odds, say so and discuss why. Speculation is appropriate in this section, but not in the observations.

Chapter 8 - Preparing Publications

Why Write Reports/Papers?

We “do” science (i.e., conduct experiments) to answer questions relevant to our field of study. The next question is “what do we do with the science?” You need to get the word out about your findings to the scientific community and the general population. This is generally accomplished by writing papers (in scientific and popular magazines), giving speeches at conferences, giving interviews, and through other routes. This document will discuss the preparation of laboratory reports and documents that will be sent for publishing in scientific journals. Here’s a quote I found on a web page that sums it all up: "The preparation of a scientific paper has almost nothing to do with literary skill. It is a question of organization." Sometimes guidelines are provided that you need to adhere to. For example, if you are submitting an article to a journal, refer to the instructions to authors usually printed in the first or last issue of the year.

The Science Paper

The typical science paper is broken up into the following sections: Title, Abstract, Introduction, Methods, Results, and Discussion/Conclusions. Sometimes the Results and Discussion sections are combined into one section (check with the particular journal you are submitting to). Each of these sections will be described below.

Title

This is the first thing the reader will see so make it good. It is what he/she will use to decide whether they will read the report or not. Describe the contents of the work clearly and precisely. Most journals require you to provide keywords for indexing purposes. Pick out 5 or so words that you think describe your work best. Avoid wasted words such as "studies on," "an investigation of." So, for example, instead of saying “An Investigation of the Effects of A on B”, say “The Effects of A on B.” Avoid abbreviations and jargon as much as possible. Avoid "cute" titles; the people reading your papers are scientists who are usually not flattered or interested in “smart” titles. They just want to you know what you did. Here are some examples that will help you:

UNACCEPTABLE

An Investigation of Hormone Secretion and Weight in Rats

Fat Rats: Are Their Hormones Different?

Bioavailability of metals in soils

Behavior of Organics in Porous Media

ACCEPTABLE

The Relationship of Luteinizing Hormone to Obesity in the Zucker Rat

Bioavailability of Cu, Zn, and Pb to *E. Coli* from Pt. Mugu Sediments

Sorption of Naphthalene and Phenanthrene in Borden Sand

Abstract

The abstract is one of the most important parts of your report. This is probably what people will read first to decide whether they would like to continue reading the paper. The abstract is the whole report in miniature, minus specific details. You need to state main objectives. Answer questions such as “what did you investigate and why?” Describe the methods briefly. Don’t include a lot of details on the actual procedures but include enough for someone to know if this was a lab experiment, field work, what methods were used (if common methods were used), etc. Answer the question “What did you do?” Summarize the most important results briefly. State the major conclusions and significance written in the Discussion portion of the report. Answer the following question: What do your results mean? So what? Do not include references to figures, tables, or sources; the reader will find these in the actual paper. Do not include information not in paper because the readers will be looking for this info. If it’s important enough to be in the abstract, it should be in the paper. Find out the maximum length (usually from 50 to 300 words) and stick to these guidelines.

You should write the abstract after you have finished the paper or the report. Once the main body is written, go back and extract key points from each section. Take these key points and put them together as your abstract. Condense and restate these points in successive revisions until you meet the word limits. At this point, you should re-read the abstract a few times to make sure it is saying what you want it to say concisely, clearly, and definitively.

Introduction

Here is where you tell the reader why you did what you did. Tell them what the overall problem was and why the problem existed (or exists) in the first place. Describe the problem investigated thoroughly without boring your reader. In this section, you need to summarize the relevant research to provide context, key terms, rationale, and concepts so your reader can understand the experiment. This section includes discussions from articles, reports, presentations, and other publications produced by you and others in the field. You need to do a lot of literature work (i.e., searchers, reading, etc.) to write this section properly. However, you should have already completed a thorough literature search before you started the project. This is probably a good time to do another search in case you have missed things in the meanwhile. The literature work will answer the following questions: What conflict or unanswered question, untested population, untried method in existing research does your experiment address? What findings of others are you challenging or extending? Describe why this work is important and include a discussion on what solution or steps toward a solution you are proposing.

Briefly describe your experiment: hypothesis or hypotheses, research question(s); general experimental design or method; justification of method if alternatives exist. This section should move from the general to the specific. Start with the problems in the real world; move to research in the literature; end with to your experiments. For example: “Groundwater contamination is a widespread problem. … Bush and Chaney (1999) showed that naphthalene stays in aquifers for many decades. … This work extends previous work …”. Try to make the reader care for your work. Make clear the links between problem and solution, question asked and research design, prior research and your experiment. Be selective, not exhaustive, in choosing studies to cite and amount of detail to include. In general, the more relevant an article is to your study, the more space it deserves and the later in the Introduction it appears.

Methods or Materials and Methods

Here is where you describe all the instruments, chemicals, supplies, equipment, and other related things you used to conduct your study. Also, you should include a thorough discussion of the methods used. Basically, you want to answer the following questions: How did you study the problem? What did you use? What materials, subjects, and equipment (chemicals, experimental animals, apparatus, etc.) did you use? How did you proceed? What steps did you take?

Provide enough detail for someone else to be able to read your paper and do the same exact experiment in the same exact way. For a journal article, include, for example, genus, species, strain of organisms; their source, living conditions, and care; and sources (manufacturer, location) of chemicals and apparatus. Order procedures chronologically or by type of procedure (subheaded) and chronologically within type. Use past tense to describe what you did. Quantify when possible: concentrations, measurements, amounts (all metric); times (24-hour clock); temperatures (centigrade). Don't include details of common statistical procedures. Don't mix results with procedures.

When you read others' papers, this is the section you scrutinize so be sure that others are scrutinizing your Materials and Methods section. Also, good lab notebook practices (described above) make writing this section very easy. On the other hand, if you don't have good notes, it becomes really hard to remember what you did, when you did it, and how you did it.

Results and Discussion

The results and discussion sections of a paper are usually separated. However, some journals (actually a trend nowadays) prefer to have the discussion intertwined with the results. I will separate them here but putting them together should be relatively easy.

RESULTS

In this section, you will describe the results obtained in your experiments. Usually, tables and figures will be presented and the data within them will be described. For each experiment or procedure, start with a brief description of the experiment without the detail of the Methods section (a sentence or two). Then, report the main result(s), supported by selected data (presented in a table or figure). The selected data should be representative of the most common result obtained in the laboratory. Choose the best example of the point you are trying to illustrate. Order results from the most to the least important and from the simple to the complex. Use past tense to describe what happened. Don't simply repeat table or figure data; select the most important features of it and report those. Don't interpret the results unless the discussion section is intertwined with the results. Avoid extra words. For example, instead of writing "Figure 1 shows that A is related to B" you can write: "A is related to B (Figure 1)." Clarify aspects of the figures or tables that you think are unclear or need explanation

DISCUSSION

In this section, you discuss what your observations mean. Here, you should summarize the most important findings. For each major result, try answering the following questions:

- What conclusions can you draw?
- What patterns, principles, and relationships do your results show?
- How do results relate to expectations and to literature cited in the Introduction?
- What plausible explanations are there?
- What additional research might resolve contradictions or explain exceptions?
- How do your results fit into a broader context?
- What theoretical implications do your results have?
- What practical applications might your results have?
- Can you extend your findings to other situations, other species?
- Do your results help us understand a broader topic?

The discussion should move from the specific to the general (opposite of the Introduction). Start with your findings, move to the literature (related to Introduction), and end with theories or issues related to the practical aspects of your results. Did the study achieve the goal (resolve the problem, answer the question, support the hypothesis) presented in the Introduction? Make explanations complete. Give evidence for each conclusion (data from Results section). This is really easy if the Results and Discussion sections are together. In this case, you can say "A caused B (Figure X). From these results (or from the data) we conclude that B is related to A." Discuss possible reasons for expected and unexpected findings. Be specific with your discussion. Don't ignore deviations in your data because you can be sure that someone else is scrutinizing your work. If you are not addressing something obvious in your data, then the person reading your paper will think you have purposefully ignored the “bad” parts of your work. This is unacceptable behavior for scientists. Avoid speculation that cannot be tested in the foreseeable future.

References

1. Writing the Laboratory Notebook” by Howard M. Kanare (ACS, 1985)

2. Rudney, G. L., & Guillaume, A. M. (2003). *Maximum Mentoring: An Action Guide for Teacher Trainers and Cooperating Teachers*. Thousand Oaks, CA: Corwin Press.