Moore Lab Packet

For

Successful Graduate Students

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Read, memorize, live

Being Legendary and Mythical
SOME MODEST ADVICE FOR GRADUATE STUDENTS

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Always Prepare for the Worst

Some of the greatest catastrophes in graduate education could have been avoided by a little intelligent foresight. Be cynical. Assume that your proposed research might not work, and that one of your faculty advisors might become unsupportive - or even hostile. Plan for alternatives.

Nobody Cares About You

In fact, some professor care about you and some don't. Most probably do, but all are busy, which means in practice they cannot care about you because they don't have the time. You are on your own, and you had better get used to it. This has a lot of implications. Here are two important ones:

1) You had better decide early on that you are in charge of your program. The degree you get is yours to create. Your major professor can advise you and protect you to a certain extent from bureaucratic and financial demons, but he should not tell you what to do. That is up to you. If you need advice, ask for it: that's his job.

2) If you want to pick somebody's brains you'll have to go to him or her, because they won't be coming to you.

You Must Know Why Your Work is Important

When you first arrive, read and think widely and exhaustively for a year. Assume that everything you read is hogwash until the author managed to convince you that it isn't. If you do not understand something, don't feel bad - it's not your fault, it's the author's. He didn't write clearly enough.

If some authority figure tells you that you aren't accomplishing anything taking courses and you aren't gathering data, tell him what you're up to. If he persists tell him to bug off, because you know what you're doing, dammit.
This is a hard stage to get through because you will feel guilty about not getting on your own research. You will continually be asking yourself, "What and I doing here?" Be patient. This stage is critical to your personal development and to maintaining the flow of new ideas into science. Here you decide what constitutes an important problem. You must arrive at this decision independently for two reasons. First, if someone hands you a problem, you won't feel that it is yours, you won't have that possessiveness that makes you want to work on it, defend it, fight for it, and make it come out beautifully. Secondly, your Ph.D. work will shape your future. It is your choice of a field in which to carry out a life's work. It is also important to the dynamic of science that your entry be well thought out. This is one point where you can start a new area of research. Remember, what sense does it make to start gathering data if you don't know - and I mean really know - why you're doing it?

**Psychological Problems are the Biggest Barriers**

You must establish a firm psychological stance early in your graduate career to keep from being buffeted by the many demands that will be made on your time. If you don't watch out, the pressures of course work, teaching, language requirements and who know what else will push you around like a large, docile molecule in Brownian motion. Here are a few things to watch out for:

1. The initiation-rite nature of the Ph.D. and it's power to convince you that your value as a person is being judged. No matter how hard you try, you won't be able to avoid this one. No one does. It stems from the open-ended nature of the thesis problem. You have to decide what a "good" thesis is. A thesis can always be made better, which gets you into an infinite regress of possible improvements.

Recognize that you cannot produce a "perfect" thesis. There are going to be flaws in it, as there are in everything. Settle down to make it as good as you can within the limits of time, money, energy, encouragement, and thought at your disposal.

You can alleviate this problem by jumping all the explicit hurdles early in the game. Get all of your course requirements and examinations out of the way as soon as possible. Not only do you thereby clear the decks for your thesis, but you also convince yourself, by successfully jumping each hurdle, that your probably are good enough after all.

2. Nothing elicits dominant behavior like subservient behavior. Expect and demand to be treated like a colleague. The paper requirements are the explicit hurdle you will have to jump, but the implicit hurdle is attaining the status of a colleague. Act like one and you'll be treated like one.

3. Graduate school is only one of the tools that you have at hand for shaping your development. Be prepared to quit for awhile if something better comes up. There are three good reasons to do this.
First, a real opportunity could arise that is more productive and challenging than anything you could do in graduate school and that involves a long enough block of time to justify dropping out. Examples include field work in Africa on a project not directly related to your Ph.D. work, a contract for software development, an opportunity to work as an aide in the nation's capital in the formulation of science policy, or an internship at a major newspaper or magazine as a science journalist.

Secondly, only be keeping this option open can you function with true independence as a graduate student. If you perceive graduate school as your only option, you will be psychologically labile, inclined to get a bit desperate and insecure, and you will not be able to give your best.

Thirdly, if things really are not working out for you, then you are only hurting yourself and denying resources to others by staying in graduate school. There are a lot of interesting things to do in life besides being a scientist, and in some the job market is a lot better. If science is not turning you on, perhaps you should try something else. However, do not go off half-cocked. This is a serious decision. Be sure to talk to fellow graduate students and sympathetic faculty before making up your mind.

Avoid taking Lectures - They're Usually Inefficient

If you already have a good background in your field, then minimize the number of additional courses you take. This recommendation may seem counter-intuitive, but it has a sound basis. Right now, you need to learn how to think for yourself. This requires active engagement, not passive listening and regurgitation.

To learn to think, you need two things: large blocks of time, and as much one-on-one interaction as you can get with someone who thinks more clearly than you do.

Courses just get in the way, and if you are well motivated, then reading and discussion is much more efficient and broadening than lectures. It is often a good idea to get together with a few colleagues, organize a seminar on a subject of interest, and invite a few faculty to take part. They'll probably be delighted. After all, it will be interesting for them, they'll love your initiative - and it will give them credit for teaching a course for which they don't have to do any work. How can you lose?

These comments of course do not apply to courses that teach specific skills: e.g., electron microscopy, histological technique, scuba diving.
Write a Proposal and Get it Criticized

A research proposal serves many functions.

1. By summarizing your year’s thinking and reading, it ensures that you have gotten something out of it.

2. It makes it possible for you to defend your independence by providing a concrete demonstration that you used your time well.

3. It literally makes it possible for others to help you. What you have in mind is too complex to be communicated verbally - too subtle, and in too many parts. It must be put down in a well-organized, clearly and concisely written document that can be circulated to a few good minds. Only with a proposal before them can the give you constructive criticism.

4. You need practice writing. We all do.

5. Having located your problem and satisfied yourself that it is important, you will have to convince your colleagues that you are not totally demented and, in fact, deserve support. One way to organize a proposal to accomplish this goal is.

   a. A brief statement of what you propose, couched as a question or hypothesis.

   b. Why it is important scientifically, not why it is important to you personally, and how it fits into the broader scheme of ideas in your field.

   c. A literature review that substantiates (b).

   d. Describe your problem as a series of subproblems that can each be attacked in a series of small steps. Devise experiments, observations or analyses that will permit you to exclude alternatives at each stage. Line them up and start knocking them down. By transforming the big problem into a series of smaller ones, you always know what to do next, you lower the energy threshold to begin work, you identify the part that will take the longest or cause the most problems, and you have available a list of things to do when something doesn't work out.

6. Write down a list of the major problems that could arise and ruin the whole project. Then write down a list of alternatives that you will do if things actually do go wrong.

7. It is not a bad idea to design two or three projects and start them in parallel to see which one has the best practical chance of succeeding. There could be two or three model systems that all seem to have equally good chances on paper of providing appropriate tests for your ideas, but in fact practical problems may exclude some of
them. It is much more efficient to discover this at the start than to design and execute two or three projects in succession after the first fails for practical reasons.

8. Pick a date for the presentation of your thesis and work backwards in constructing a schedule of how you are going to use your time. You can expect a stab or terror at this point. Don't worry - it goes on like this for awhile, then it gradually gets worse.

9. Spend two to three weeks writing the proposal after you've finished your reading, then give it to as many good critics as you can find. Hope that their comments are tough, and respond as constructively as you can.

10. Get at it. You already have the introduction to your thesis written, and you have only been here 12 to 18 months.

Manage Your Advisors

Keep your advisors aware of what you are doing, but do not bother them. Be an interesting presence, not a pest. At least once a year, submit a written progress report 1-2 pages long on your own initiative. They will appreciate it and be impressed.

Anticipate and work to avoid personality problems. If you do not get along with your professors, change advisors early on. Be very careful about choosing your advisors in the first place. Most important is their interest in your interest.

Types of Theses

Never elaborate a baroque excrescence on top of existing but shaky ideas. Go right to the foundations and test the implicit but unexamined assumptions of an important body of work, or lay the foundations for a new research thrust. There are, of course, other types of theses:

1. The classical thesis involves the formulation of a deductive model that makes novel and surprising predictions which you then test objectively and confirm under conditions unfavorable to the hypothesis. Rarely done and highly prized.

2. A critique of the foundations of an important body of research. Again, rare and valuable and a sure winner if properly executed.

3. The purely theoretical thesis. This takes courage, especially in a department loaded with bedrock empiricists, but can be pulled off if you are genuinely good at math and logic.
4. Gather data that someone else can synthesize. This is the worst kind of thesis, but in a pinch it will get you through. To certain kinds of people lots of data, even if they don't test a hypothesis, will always be impressive. At least the results show that you worked hard, a fact with which you can blackmail your committee into giving you the doctorate.

There are really as many kinds of theses as there are graduate students. The four types listed serve as limited cases of the good, the bad and the ugly. Doctoral work is a chance for you to try you had at a number of different research styles and to discover which suits you best: theory, field work, or lab work. Ideally, you will balance all three and become the rare person who can translate the theory for the empiricists and the real world for the theoreticians.

Start Publishing Early

Don't kid yourself. You may have gotten into this game out of love for plants and animals, your curiosity about nature, and your drive to know the truth, but you won't be able to get a job and stay in it unless you publish. You need to publish substantial articles in internationally recognized, referred journals. Without them, you can forget a career in science. This sounds brutal, but there are good reasons for it, and it can be a joyful challenge and fulfillment. Science is shared knowledge. Until the results are effectively communicated, they in effect do not exist. Publishing is part of the job, and until it is done, the work is not complete. You must master the skill of writing clear, concise, well-organized scientific papers. Here are some tips about getting into the publishing game.

1. Co-author a paper with someone who has more experience. Approach a professor who is working on an interesting project and offer your services in return for a junior authorship. He'll appreciate the help and will give you lots of comments on the paper because his name will be on it.

2. Do not expect your first paper to be world-shattering. A lot of eminent people began with a minor piece of work. The amount of information reported in the average scientific paper may be less than you think. Work up to the major journals by publishing one or two short - but competent - papers in less well-recognized journals. You will quickly discover that no matter what the reputation of the journal, all editorial boards defend the quality of their project with jealous pride - and they should!

3. If it is good enough, publish your research proposal as a critical review paper. If it is publishable you've probably chosen the right field to work in.

4. Do not write your thesis as a monograph. Write it as a series of publishable manuscripts, and submit the early enough so that at least one or two chapters of your thesis can be presented as reprints of published articles.
5. Buy and use a copy of Strunk and White's Elements of Style. Read it before you sit down to write your first paper, then read it again at least once a year for the next three or four years. Day's book, How to Write and Publish a Scientific Paper, is also excellent.

6. Get your work reviewed before you submit it to the journal by someone who has the time to criticize your writing as well as your ideas and organization.

**Don't Look Down on a Master's Thesis**

The only reason not to do a master's is to fulfill the generally false conceit that you're too good for that sort of thing. The master's has a number of advantages.

1. It gives you a natural way of changing schools if you want to. You can use this to broaden your background. Moreover, your ideas on what constitutes an important problem will probably be changing rapidly at this stage of your development. Your knowledge of who is doing what, and where, will be expanding rapidly. If you decide to change universities, this is the best way to do it. You leave behind people satisfied with your performance and in a position to provide well-informed letters of recommendation. You arrive with most of your Ph.D. requirements satisfied.

2. You get much-needed experience in research and writing in a context less threatening than doctoral research. You break yourself in gradually. In research, you learn the size of a soluble problem. People who have done master's work usually have a much easier time with the Ph.D.

3. You get a publication.

4. What's your hurry? If you enter the job market too quickly, you won't be well prepared. Better to go a bit more slowly, build up a substantial background, and present yourself a bit later as a person with more and broader experience.

**Postscript**

This comment was originally entitled "Cynical aids towards getting a graduate degree, or psychological and practical tools to use in acquiring and maintaining control over your own life." It originated as a handout for the Ecolunch Seminar in the Department of Zoology, University of California, Berkeley, on a Monday in the spring of 1976. Ecolunch was, and is, a Berkeley institution, a forum where graduate students present their work in progress and receive constructive criticism. At the start of the semester, however, no one is ready to talk. This was such a time.
On Friday morning at Museum Coffee, Frank Pitelka, who was in charge of Ecolunch for that semester, asked me to make the presentation on the following Monday. "Asked" is probably a misleading representation of Frank's style that morning. Frank bullied me into it. I had just given a departmental seminar on the Ph.D. work I had done at British Columbia, and did not have much new to say about biology. Frank's style brought out the rebel in me. I agreed on the condition that I had complete freedom to say whatever I wanted to, and that the theme would be advice to graduate students. Frank agreed without apparent qualms. Then I charged upstairs to Ray Huey's office to plot the attack.

I whipped out an outline, Ray responded with a more optimistic and complementary version (see the following Commentary article), and I wrote a draft at white heat that afternoon. We felt like plotters. There were acts of self-definition in the air. On Monday, I recall that I made a pretty aggressive presentation in which, to emphasize how busy faculty members were, I kept looking at my watch. Near the end I glanced at my watch one last time, said I had to rush off to an appointment, left the room suddenly without taking questions, and slammed the door. They waited. I never came back, but Ray took over and presented his alternative view. Ray told me later that Bill Lidicker turned to him and said, "You mean he's not coming back?" I wasn't. Fortunately, they took it well. They were and are a group of real gentlemen.

I mention these things to explain the tone of our pieces. We would not write them that way now, having been professors ourselves for some years. We never intended to publish them, having regarded the presentations as a one-time skit, but our notes were xeroxed and passed around, and eventually they spread around the United States. In the fall of 1986 I got a letter from Pete Morin at Rutgers suggesting that we publish the notes. Its survival for ten years in the graduate student grapevine convinced me that there might actually be a demand for them. I had lost my original, and Pete kindly sent me a copy, which turned to be a nth generation version with marginal notes by a number of different graduate students. On rereading it, I find that I agree with the basic message as much as ever, but that many of the details do not apply outside the context of large American universities.

Ten years later, I have one after-thought.

**Publish Regularly, but Not Too Much**

The pressure to publish has corroded the quality of journals and the quality of intellectual life. It is far better to have published a few papers of high quality that are widely read, then it is to have published a long string of minor articles that are quickly forgotten. You do have to be realistic. You will need publications to get a post-doc, and you will need more to get a faculty position and then tenure. However, to the extent that you can gather your work together in substantial packages of real quality, you will be doing both yourself and your field a favor.
Most people publish only a few papers that make any difference. Most papers are cited little or not at all. About 10% of the articles published receive 90% of the citations. A paper that is not cited is time and effort wasted. Go for quality, not for quantity. This will take courage and stubbornness, but you won't regret it. If you are publishing one or two carefully considered, substantial papers in good, refereed journals each year, you're doing very well - and you've taken enough time to do the job right.

Acknowledgments

Thanks to Frank Pitelka for providing an opportunity, to Ray Huey for being a co-conspirator and sounding board and for providing a number of the comments presented here, to the various unknown graduate students who kept these ideas in circulation during the last decade, and to Pete Morin for suggesting that we write them for publication.

Some Useful References


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Preface

When Steve showed me the preliminary outline for his talk, my first response was to say, "Steve, this is really cynical, even by your standards! You can't possibly present such a negative view of graduate education." My second response was to draft an alternative outline, which I intended as a direct challenge to Steve's, and which I presented after Steve so rashly stormed out of Ecolunch.

A decade has passed since we performed that amusing skit. In transcribing our old outlines into text, Steve and I have tried to preserve the intentionally argumentative, point-counterpoint format and flavor of our original presentations. We do so, not because we remain convinced that our old views are necessarily correct (I am pleased to note that Steve now recants his views, at least in part), but because we want to emphasize a diversity of views of how to be a graduate student.

Our main point is this: there is no one way to be a graduate student. Each of us is an individual - each of us has individual needs, goals, capacities, and experiences. Advice that is productive for one student may be disastrous for another. So think about these and other views, but don't accept them without question.

Initial Premise

Graduate school provides an opportunity for you to change from being someone who reads to someone who is read. That is a major metamorphosis, indeed. Not surprisingly, it presents challenges as well as opportunities.

Always Expect the Best

If you anticipate the worst, you are likely to experience it. Instead, develop a positive attitude, decide what you want (T.A. position, research funds, etc.), and then get it. Go outside your university whenever possible for advice and for funds. Don't merely rely on your major professor. In short, be active and independent, not passive and dependent.
Some People Do Care

People are more likely to care about you if you act like a professional (see below) and if you make yourself valuable. Obtain a skill (multivariate statistics, electrophoresis) that you can share (and of course yourself). Avoid being used, however.

Seek out and collaborate with fellow graduate students, especially ones who are doing interesting work and who are enjoying it. You are likely to learn far more from graduate students than from your advisor, if only because you have more in common and spend more time with them. In short, use these interactions as an opportunity to be introduced to different viewpoints and techniques and to become excited about your career.

Seek out emeritus or near-emeritus professors, at least ones who are still active. They have a wealth of knowledge and experience, and often have the time and interest to share it. Moreover, they can give you a personal appreciation for the history of your field. Science is an historical activity, and progress in science is often enhanced by an understanding of the past.

On "Exhaustive" Thinking

Thinking "widely and exhaustively" can be mentally exhausting if you aren't academically and emotionally prepared. You may instead make better use of your first year by making up deficiencies in your course background (do so as quickly as possible!). Moreover, some people simply need time before they are ready to think independently. That maturation process can sometimes be accelerated by starting your research with a problem that your advisor "hands you."

Ultimately, however, you must begin to think and do research independently, and you must understand why you are doing a particular project.

On Psychological Problems

Expect them. Everyone will go through periods of intellectual insecurity or stress, most likely in the first year or two. You can often minimize these problems with some simple tricks.

1. Get requirements out of the way as soon as possible. You will be surprised at how much your attitude toward graduate school and your research will improve once you pass all language requirements and qualifying exams. Keep in mind that faculty are inevitably impressed by students who aren't intimidated or slowed down by academic hurdles.

2. Some people simply need time to mature academically. So, fight directives and pressure to complete your Ph.D. in 4 years. You may need to take some extra time or even take a leave of absence. Changing schools or advisors sometimes helps, especially if you can first obtain a Master's degree.
Becoming a Professional

Think of yourself as a professional, someone who will be a biologist for the rest of your life. Start to accumulate a library and reprint collection, develop a computerized list of references and addresses, attend meetings, meet with visiting seminar speakers, correspond with people working on related problems, send out copies of your articles as they are published, etc.

Treat each project (even a literature review) as if it is potentially publishable.

Faculty are more likely to treat you as a professional if you act like one. They are a good source of suggestions in this regard. Ask their advice on efficient ways to organize your reprints and reference files, or ask them to recommend key papers (their own, or those of others) that influenced their thinking and careers. Read those papers, then go back and discuss them with the professor. (Note: Many graduate students have not read most of their advisor's papers, or those of other relevant faculty in their department.)

Despite your best efforts (and theirs), the faculty may have a difficult time treating you as a colleague rather than as a student. Therefore, develop contacts outside of the department and the university, thereby gaining a new perspective on biology and on your own work. Go on a tour of other universities, meet with faculty and students working in your area, volunteer (if appropriate) to give an informal seminar of your thesis work. If possible, spend a term and take courses at another university (or a field station), especially if a course is special and especially if you are spending your graduate career at one university. These outside contacts not only broaden your perspectives but may also increase your chances for a collaborative research project, a postdoc, or even a job.

Join appropriate scientific societies, attend their yearly meetings, give papers or posters, get to know your future colleagues. Meetings can be exciting and a chance to find out what is new. Moreover, you get practice at speaking in front of a "foreign" (e.g., nonsympathetic audience).

On Courses

Never pass up a lecture course from a great professor, even if it is somewhat outside your main area. Seek courses that challenge you to think rather than to memorize. Auditing courses can often be an efficient way to get an overview of a field, at least if you are self-disciplined.

Take short courses that can save you time over the years. Many libraries give instruction on efficient literature searches (see also Smith's book, cited by Steve); and most universities offer introductions to computers, statistical packages, etc. If you don't know these critical skills already, immediately learn speed typing and word-processing.
On Proposals and Grants

Grant writing is a key skill. Ask professors for copies of their successful grant proposals (perhaps ask for unsuccessful ones as well). In other words, find out what makes a good proposal before you start writing; don't waste time "reinventing the wheel."

Be a scholar. Showing that you know and understand the literature makes a good impression, and it gives you an awareness of the key issues in your field.

Use the working proposal Steve describes as a basis for a real grand proposal. Many societies, government agencies (NSF), and organizations give grants to graduate students - ask your major professor and other graduate students for the names of such organizations. Prod your department or advisor to start a permanent file on such grants.

Getting your own grant has important benefits beyond simply funding your research. (1) It gives you something to add to your C.V. (2) It helps establish your independence from your advisor and your department. (3) It really impresses your advisor and your committee!

Interactions with Your Advisors

(Tangent. Even after a decade, I can still hear Steve pontificating the first sentence in this section. His expression, "a baroque excrescence," is my fondest auditory memory of Berkeley.)

Onward. A thesis shouldn't be a culmination of your research career, but its beginning. You probably never really had your creativity challenged as an undergraduate. Here is your opportunity. Push yourself - you'll respect yourself more than if you are too cautious and try a no-risk project.

Remember that your future research directions need not be constrained by the topic of your thesis. In fact, your thesis experiences may convince you that your interests and talents are elsewhere. Use a Master's-to-Ph.D. switch or a postdoc to change directions, if appropriate.

Publishing

Contrary to widespread opinion, writing and publishing can be fun. More important, the process of writing is a positive learning experience - my understanding of my own research is invariably enhanced while developing a paper or grant proposal.

Writing and publishing aren't always fun, of course, but you can minimize problems by being careful, by organizing your thoughts before you write, by taking pride in crafting sentences carefully, and by having people critically review your papers before you submit them for publication. This review process should be sequential: First, give it at an "Ecolunch." Second, write a draft and have your fellow graduate students and advisor review it critically. Third
(optional, but advised), send it to one or a few experts in the field. Fourth, submit the manuscript.

(Having now been an editor of several journals and books, I would add several caveats. Make certain you follow the "Instructions to Authors" for the journal: If you use the wrong format, the editor will suspect that (1) your paper was previously rejected by another journal, or that (2) your work style is casual and not necessarily to be trusted. Also, carefully check the citations in the text against the literature cited section. Check text, tables, and figures for accuracy and neatness. (A paper that is neat and well designed is easy to read.) If you are writing an invited chapter for a book, do your very best to meet all deadlines. Editors cherish contributors who actually meet deadlines and follow instructions.)

Publishing is an important responsibility - you share your insights with others. It is also essential. People occasionally get good jobs or a grant despite of a weak or nonexistent list of publications, but the odds of this happening are slim, indeed.

Although over-publishing is a mistake (as Steve notes) don't be embarrassed by writing one or a few minor papers - ample precedent exist. Moreover, we are often our own worst judge of what is truly significant (see Bartholomew 1982). (After gaining the benefits of the experience, you can eventually obscure any truly trivial publications by using the following widely used technique - simply change your official "List of Publications" to a "Selected List of Publications" or to a "List of Publications since 19xx"!)

Miscellaneous

Watch for and take advantage of opportunities. If someone is organizing a special field trip, ask if you can go along and help. If there is a job search in your department, look through the applications and learn first hand what makes a good C.V. and what makes a clear statement of research and teaching interests. (Note: Not all departments permit graduate students to read application files.) Find out your advisor's opinion of the candidates' job seminars. Thus when you start applying for jobs, you will have some idea of what works and what doesn't.

Concluding Remarks

Appearances to the contrary, graduate students need not be oppressed. You actually have as much freedom as you ever have (except perhaps as a postdoc or during a precious sabbatical). Be positive, not cynical.

Postscript

"Ten years later," I wish to emphasize one comment and then make one addition. First, do spend time around students and faculty who are doing significant research and who are
excited about their careers. In short, surround yourself with good people. Enthusiasm is contagious. Second, learn to respect and to practice the art of being organized. Thus, be efficient and don't waste time. This will almost certainly enhance your productivity and your enthusiasm for your career.

Acknowledgments

I am, of course, grateful to Steve Sterns, whose outrageous views prompted this reply. T. Garland, Jr. made useful comments on a draft.

Literature Cited


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I recently saw an old friend for the first time in many years. We had been Ph.D. students at the same time, both studying science, although in different areas. She later dropped out of graduate school, went to Harvard Law School and is now a senior lawyer for a major environmental organization. At some point, the conversation turned to why she had left graduate school. To my utter astonishment, she said it was because it made her feel stupid. After a couple of years of feeling stupid every day, she was ready to do something else.

I had thought of her as one of the brightest people I knew and her subsequent career supports that view. What she said bothered me. I kept thinking about it; sometime the next day, it hit me. Science makes me feel stupid too. It’s just that I’ve gotten used to it. So used to it, in fact, that I actively seek out new opportunities to feel stupid. I wouldn’t know what to do without that feeling. I even think it’s supposed to be this way. Let me explain.

For almost all of us, one of the reasons that we liked science in high school and college is that we were good at it. That can’t be the only reason – fascination with understanding the physical world and an emotional need to discover new things has to enter into it too. But high-school and college science means taking courses, and doing well in courses means getting the right answers on tests. If you know those answers, you do well and get to feel smart.

A Ph.D., in which you have to do a research project, is a whole different thing. For me, it was a daunting task. How could I possibly frame the questions that would lead to significant discoveries; design and interpret an experiment so that the conclusions were absolutely convincing; foresee difficulties and see ways around them, or, failing that, solve them when they occurred? My Ph.D. project was somewhat interdisciplinary and, for a while, whenever I ran into a problem, I pestered the faculty in my department who were experts in the various disciplines that I needed. I remember the day when Henry Taube (who won the Nobel Prize two years later) told me he didn’t know how to solve the problem I was having in his area. I was a third-year graduate student and I figured that Taube knew about 1000 times more than I did (conservative estimate). If he didn’t have the answer, nobody did.

That’s when it hit me: nobody did. That’s why it was a research problem. And being my research problem, it was up to me to solve. Once I faced that fact, I solved the problem in a couple of days. (It wasn’t really very hard; I just had to try a few things.) The crucial lesson was that the scope of things I didn’t know wasn’t merely vast; it was, for all practical purposes, infinite. That realization, instead of being discouraging, was liberating. If our ignorance is infinite, the only possible course of action is to muddle through as best we can.

I’d like to suggest that our Ph.D. programs often do students a disservice in two ways. First, I don’t think students are made to understand how hard it is to do research. And how very, very hard it is to do important research. It’s a lot harder than taking even very demanding courses. What makes it difficult is that research is immersion in the unknown. We just don’t know what we’re doing. We can’t be sure whether we’re asking the right question or doing the right experiment until we get the answer or the result. Admittedly, science is made harder by competition for grants and space in top journals. But apart from all of that, doing significant research is intrinsically hard and changing departmental, institutional or national policies will not succeed in lessening its intrinsic difficulty.

Second, we don’t do a good enough job of teaching our students how to be productively stupid – that is, if we don’t feel stupid it means we’re not really trying. I’m not talking about ‘relative stupidity’, in which the other students in the class actually read the material, think about it and ace the exam, whereas you don’t. I’m also not talking about bright people who might be working in areas that don’t match their talents. Science involves confronting our ‘absolute stupidity’. That kind of stupidity is an existential fact, inherent in our efforts to push our way into the unknown. Preliminary and thesis exams have the right idea when the faculty committee pushes until the student starts getting the answers wrong or gives up and says, ‘I don’t know’. The point of the exam isn’t to see if the student gets all the answers right. If they do, it’s the faculty who failed the exam. The point is to identify the student’s weaknesses, partly to see where they need to invest some effort and partly to see whether the student’s knowledge fails at a sufficiently high level that they are ready to take on a research project.

Productive stupidity means being ignorant by choice. Focusing on important questions puts us in the awkward position of being ignorant. One of the beautiful things about science is that it allows us to bumble along, getting it wrong time after time, and feel perfectly fine as long as we learn something each time. No doubt, this can be difficult for students who are accustomed to getting the answers right. No doubt, reasonable levels of confidence and emotional resilience help, but I think scientific education might do more to ease what is a very big transition: from learning what other people once discovered to making your own discoveries. The more comfortable we become with being stupid, the deeper we will wade into the unknown and the more likely we are to make big discoveries.
Prospectus on Graduate Studies and Advising
Dan Binkley (dan@cnr.colostate.edu)

The quality of a graduate education depends in part on the quantity and quality of interactions between students and advisors (and between students and students!). Each student’s experience in graduate education is unique, and advising expectations need to be developed through discussions between the student and advisor. This prospectus gives my general view of graduate education, providing a starting point for developing programs that suit each student.

Philosophy:

Graduate education deals with developing knowledge, the ability to use knowledge, and the ability to think with creativity and skepticism. A Masters level education aims to develop a student’s ability to participate in science, typically at the level of applying science (to natural resource issues, for example). A doctoral level education aims to produce scientists (professional or avocational). I have high expectations for student accomplishments, and work to help students achieve their goals.

A doctoral program is qualitatively different from a masters program – not just more of the same. Differences include greater rigor for a PhD -- not just in hours expended, but in accomplishments and abilities as a scientist.

Students gain knowledge and understanding from many parts of a university -- by hanging out with fellow students, in classes, in journals, and in research projects.

The advisor serves a double role in graduate programs. As a mentor, the advisor supports, encourages and nurtures each student’s development. As a professor, the advisor also judges the accomplishment and potential of each student. Students should expect support from advisors, but this support may sometimes include uncomfortable criticism and challenges. Some students begin graduate work with a vision that turns out not to match the real program – such as the program requiring greater dedication, sharper thinking, broader knowledge, more skills in math or chemistry. The advisor is responsible for helping students develop their visions and accomplishments to meet the demands of the program. On rare occasion, the match just doesn’t come, and the student and advisor need to discuss a transition out of the program.

Expectations for MS level students:

A student completing an MS program should:
   A. Have personal motivation, curiosity, and enthusiasm for learning science;
   B. Have a general, working knowledge of science, including its philosophy, methods, and current state;
   C. Have a solid understanding of the state of science within the area of his or her interest;
   D. Be able to understand and use basic statistics, sampling procedures, and analytical methods;
   E. Be able to communicate clearly and effectively, in written and oral presentations;
   F. Begin to read the literature; and
G. Reach these milestones:
   1. Coursework plan developed by end of first semester.
   2. Research plan developed by middle of second semester; file GS-6 form.
   3. Steady progress on research
   4. Submission of at least one paper for publication by the time of graduation, with a second near-ready for submission (alternatively, one large paper would be fine).

Expectations for PhD level students:

A student completing a PhD program should:

A. Have personal motivation, curiosity, and enthusiasm for becoming a scientist;
B. Have a broad knowledge of the philosophy, history, and current state of science;
C. Be competent in major techniques used in ecological research, including statistical, field, and laboratory methods;
D. Be an expert in the state of science within his or her specialty – ideally knowing more about the subject than the advisor knows!
E. Be able to think clearly, critically, and creatively – beyond the level expected for MS-level students;
F. Routinely read the literature;
G. Be able to communicate clearly and effectively, in written and oral presentations; and
H. Reach these milestones:
   1. Coursework plan developed by end of first semester;
   2. Research plan developed by end of second semester; file GS-6 form;
   3. Steady progress on research; and
   4. Submission of one review paper for publication, and one original research paper before graduation; at least 2 more papers ready to submit near the time of graduation. For diversity, one original-data paper should deal with a topic outside the dissertation field. The number of papers would of course be flexible in cases where large (monograph) papers are produced. NOTE: The people who get good jobs tend to have 50-100% beyond this level of paper production during their PhD programs. Do you want a job?

Expectations for advising:

The graduate advisor should:

A. Take a personal interest in each student’s education, including goals, areas of interest, and abilities;
B. Challenge each student to achieve;
C. Provide feedback on progress, critique written and oral presentations; a 2-week (or less) turnaround on review of student paper should be expected.
D. Provide insights on the inner workings of science – funding, personalities, publications, manuscript review and publication, proposal writing;
E. Financial support (to the extent possible), including tuition, stipend, research funds and travel to a variety of ecosystems and scientific meetings.

**Workload:**

If a student uses graduate school to advance toward career goals, it’s important to develop a clear idea of the professional playing field. Good job openings have many well-qualified competitors; a graduate program needs to produce graduates who are well positioned to win the competition. Four points of successful preparation for the job arena are:

A. Number of publications.
B. Presentations at meetings, and other direct ways of developing personal contacts with peers.
C. Quality of publications and presentations. This includes style -- but also pizzazz of the topic (hypothesis, question examined, context of the question, etc.)
D. Breadth and depth of experience, including multiple ecological questions and ecosystems.

In my experience, there are 3 "strategies" used by successful scientists:

A. I work very hard, so I’m successful.
B. I’m clever and efficient, so I’m successful.
C. I spend many hours on my favorite pastime, Science, so I’m successful even though it’s not work.

A graduate student needs to understand her own approach to the issues of how to achieve high productivity (with hours of toil, or with efficiency, or with abandon), and structure the graduate program accordingly. If a student is being very productive, I don’t care if he takes a week in August to kayak. If a student is struggling, more hours of work are probably needed. The level of fun and enjoyment one finds in the dull, daily work of ecology may be a good indicator of whether a career in this direction is a good idea.

Words of warning: If your graduate program is not fun, and you’re not being productive, think about changing career paths.

More words of warning: essentially all professional jobs in ecology require the juggling of multiple tasks daily – large blocks of time to focus on single projects are rare. Successful professionals are often good at juggling; frustrated and over-worked professionals are often poor jugglers. What’s your style?

**Where do research ideas come from?**
General guidelines include:

A. Finding a research site that is begging to be measured for a great idea. Sometimes the availability of an on-going research site provides the fertile ground for a new test of an idea.
B. Discussing the state of knowledge, esp. the limitations, with fellow students and professors. The most fertile ground is often at the juncture of 2 fields. For example, ecosystem ecologists may have one view of productivity, and physiological ecologists another – are there any areas where the two fields bring different expectations to the forest? Such junctures can also include two levels of scale – can something that looks true at one scale be different at another?
C. Find an argument in the literature, and identify the corner of reality where one theory makes a prediction that is opposed by the other – set out to falsify something. If done well, this could form the basis of a review/synthesis article to publish.
D. Think about a more complete context than the one presented in a literature debate or a current research project. “If proposition 1 is true locally, what would be the implications for expectation A over there?” For biogeochemistry, these complete contexts include conservation of matter (you can’t have a budget line item here that is inconsistent with another budget item over there…).
E. Think of an idea that we all hold to be self-evident, and ask if the evidence supports our credulity. Do we really understand the underlying processes, or just assume we do? If the expectation is logically sound, how well does the evidence support it?

Good topics have some of these characteristics:

A. The subject is of interest to peers, often with some implications for how populations, species, or ecosystems are sustained or managed.
B. Your approach is different from those used for similar questions in the past – your approach has an element of insightful testing (clarity or perhaps cleverness) that has been lacking. The power of your work might be stronger if it covers a bigger scale (working in 3 or 10 unrelated sites to test an idea), or a spatially explicit scale. Your approach would often benefit from modeling – but the value gained from modeling depends on how you go about it (in advance is better than after the fact), and whether you create the model as a constrained work of art, a tool, or a hypothesis to be falsified.
C. Your approach is risky – the idea is novel and fascinating enough that it may not be true. But what if you disprove your clever idea? I suggest 2 backup strategies: have a good descriptive story to tell (independent of the outcome of the hypothesis test), and have at least one solid side-project that can stand on its own.

One insomniacal night I typed out a list of case studies from my work (and from some of my students), identifying how the ideas developed. If you promise not to laugh, or to think the list is too biographically ego-centric, you can click on Binkley Case Studies.

Suggested Reading:

Masters students should read several of the following books (or ones on similar topics); books with asterisks are especially recommended. Doctoral students should read 2X several.
Biographies are included as a way to gain perspectives on how science really operates in social and cultural contexts.

EVERYONE with a career interest in Science should read Bill Bryson’s book, *A Short History of Nearly Everything* – this is by far the best rendition of the big picture of Life, the Universe, and Everything. An educated ecologists needs to know where she sits in the universe, and how she got there.

**Nature and history of science:**

**General science knowledge:**

**Biography:**
Curie: Marie Curie : A Life by Susan Quinn
*Pasteur: Louis Pasteur by Patrice Debrj
Leopold: Aldo Leopold : His Life and Work by Curt Meine
Darwin: Darwin: The Life of a Tormented Evolutionist by Adrian Desmond, James Moore
Huxley: Huxley: from Devil’s Disciple to Evolution’s High Priest, by Adrian Desmond.
Lovelock: Homage to Gaia, the Life of an Independent Scientist, by James Lovelock

**Ecology:**
Forest science:

English and writing:


Some Rules:

Each student benefits from our whole group, and I expect that students will be willing to help other students at particular times of need (such as a quick sampling trip that needs extra hands, or a particular lab analysis need). This also includes helping new students learn the ropes. I occasionally need help on a project that may not be directly funding a student, and I expect students to be willing to pitch in. This approach to helping others doesn’t involve great time and effort, but it contributes a great deal to morale and accomplishing our goals.

Each student is responsible for:

- Knowing the safety rules of the lab, including personal safety, chemical safety, and hazardous waste requirements.
- Helping keep the lab clean, equipment in good shape (and accounted for).
- Backing up all computer files regularly, and storing the back-up disk or tape safely (away from the computer in case of theft).

Publication – unless a student’s project is self-funded, the student has an obligation to see the work through to the end – which is defined as publication. If a student has not submitted a manuscript within a year of completion, I would like to have the right to take over the obligation. In such a case, the student would remain an author on the work – sometimes first author, sometimes second author. When I have had to write the papers from student projects, about ¾ of the time the student has remained the first author, and ¼ of the time I thought I couldn’t justify leaving the student first.

Authorship – I subscribe to the commonly held ideas in scientific societies: authorship denotes major contributions in ideas or writing. Contributions of funding or labor alone are appropriately
noted in acknowledgements. If a student develops a project very independently, I do not expect to be a coauthor. In general, I think PhD students should produce at least one substantial paper without the advisor as a coauthor. If I’m providing a good portion of the ideas or writing, then coauthorship may be appropriate. Senior authors (ie, students) should have the final say in deciding authorship; if disagreements arise, decisions should lean in favor of giving more credit to people at a junior career stage than a senior career stage.

Other ideas about graduate education from students and colleagues:

- Participation in national meetings is fundamentally important to developing a career in ecology (for insights, check out Indy Burke’s article from the ESA Bulletin).
- Coauthoring papers with other graduate students is a great idea.
- Presentations of research ideas, and research findings, to the lab group is valuable.
- Professor should launch year with an introduction to expectations, the lab, current research, issues.
- Students should take advantage of opportunities to provide guest lectures in undergraduate classes (see Dan).
- Students are expected to presentation research at the Front Range Student Ecology Symposium.
- Students should plan on presenting research at regional or national science meetings (discuss with Dan).
- Ideas on graduate study from other professors (I don’t agree with all the points – but good grist for your mill): Schulz and Knapp
Some Pragmatic Advice to Graduate Students: a Hybridization of Stearns, Huey, and Binkley

As a graduate recently completing a 10-year sojourn in post-baccalaureate study, I thought this forum appropriate to address the recent articles by Stearns (1987), Huey (1987), and Binkley (1988) on the complexities of a graduate career. I wish to reemphasize Huey’s (1987) statement that there is no single best blueprint for a successful and productive graduate career. I believe, however, that certain elements must be incorporated into any tactical attempt at completing a graduate degree in ecology.

Initial premise

Although implied by Stearns, Huey, and Binkley, I believe that this fact should be made explicit: complete dedication is essential. Anything less than a total commitment will be counterproductive. If you aren’t sure whether graduate school is the right choice for you, then it probably isn’t. Nothing is more obvious to your major advisor, committee members, and graduate student colleagues than a halfhearted effort. You will alienate everyone if you waste their precious time. Most are willing and eager to help, but it is your responsibility to prove that you merit then assistance.

Hope for the best but be prepared for the worst

Herein lies the first hybridization. Somewhere between “nobody cares about you” (Stearns 1987) and “always expect the best” (Huey 1987) lies cautious optimism. You will learn quickly in your program who can be trusted and who is a bubonic siphonapteran. Trust your instincts. When in doubt, seek the advice of your mentor first, then that of experienced graduate students if necessary. After all, only your major professor can protect you in case of a disaster such as a disgruntled, uncooperative, or offended committee member. Establish trust and candid communication with your advisor as soon as possible; they’ll go to bat for you if they’re worth their salt.

On psychological problems

As Stearns points out, the pressures inherent in a graduate career (particularly from deadlines) are enormous. You must be psychologically stable. Emotional problems with your significant other, parents, friends, or pet python will at best delay and at worst ruin your chance for completing your thesis/dissertation.

On financial stability

Unfortunately, this highly sensitive and critically important subject is not given the emphasis it rightfully deserves by either Stearns, Huey, or Binkley. Eating and paying rent (and perhaps purchasing the occasional book) are not luxuries; they are necessities. Some graduate advisors and committee members may lose sight of this fact. Financial problems are particularly acute for the contemporary graduate student who often must help support a family. Inadequate funding can exacerbate psychological problems or even force you to quit the program prematurely. I have listed below what I feel is a reasonable priority of methods to obtain funding.

1) Seek grant/fellowship support. If your department has a graduate coordinator, either they or their secretary may have a list of potential sources. If this fails, try the graduate school office of your institution. There is a plethora of possible funding sources, including NSF, NIH, and professional societies; quite often, in-house awards/fellowships are available (albeit highly competitive) from your own institution. You might also shop around your department (especially your mentor) for research assistantships.

2) Teaching assistant stipends. Although this option can provide invaluable assets such as enhancement of teaching skills (and thus your marketability), and it may provide long-term support, be forewarned that it is time-consuming. Furthermore, it probably will take you away from your research considerably more than option 1.

3) Seek part-time or, if necessary, full-time employment in an academic setting. Some universities allow graduate students to teach classes such as non-major science courses. A local junior college is another pos-
sibility. Use this option only when all else fails (and it may). This option is still superior to packing bags at the local supermarket.

Choose your major advisor carefully, before you select your institution

Although Stearns, Huey, and Binkley all stress the imperative of mutual respect between mentor and graduate student, only Steams mentions this most critical precursor: practice preventive medicine. Ask someone you trust, perhaps an undergraduate professor/counselor, about the ability of your prospective advisor to establish productive relationships with graduate students. Travel to their institution on a fact-finding tour. Meet with them personally (a phone call is not the same) and consult as many of their graduate students as possible. Chances are if most of the graduate students are notably disgruntled with their advisor, you may be as well. should you select that program.

Rely on your major advisor for informed guidance

In my opinion, any attempt to "manage your advisor" (Stearns 1987) may be misconstrued as arrogance. Although it is critical to establish your independence (particularly in terms of aggressive, logical thinking), remember one key fact: you become truly independent only after you graduate. Until you have that precious sheepskin framed and on the wall, your career is in their hands. The responsible advisor committee member will encourage increasing levels of independence as you progress. Inform your major advisor early about your perceived inadequacies and accept their guidance about which courses to take, timetables for completion of qualifying examinations and language requirements, etc. Ask to participate in their research projects. They will welcome the help and you may get a junior authorship out of the deal.

Make yourself visible to the scientific community A.S.A.P.

Publish both quality papers and minor efforts. At this point in your career, even something as trivial as a note (new technique, behavioral observation, range extension, etc.) will familiarize your future colleagues with your name. I am in complete agreement with Huey in that attending conferences, giving papers, and joining professional societies will both hone your skills (e.g., oratorical ability) and enhance your changes of completing your degree and obtaining gainful employment in your chosen profession.

Literature Cited

Brian W. Witz
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An 6-step program to choosing your PhD project

Perhaps the single most difficult thing to do during one’s graduate career is to pick an appropriate PhD project. Moreover, it is arguably the most crucial decision in one’s scientific (or in general academic) career, since it is going to affect all the major first steps after graduation (be that finding a post-doc, an initial position as a faculty or researcher, or securing funding for one’s own research).

It is therefore astounding to see how many students make such a decision on fairly shaky grounds, and even more disconcerting how so many “advisors” are of very little use in advising their pupils on such a crucial matter. This little flyer does not, obviously, pretend to provide a simple solution to the problem (there isn’t one). However, distilled below are some suggestions that should be valuable to most people embarking in an academic career.

Here it goes:

**Step I -- Determine your general area of interest**, such as ecology, evolution, molecular biology, or philosophy of science. This should be done before applying to graduate school, most effectively through a combination of broad readings and apprenticeship in one or more labs as an undergraduate student.

**Step II -- Narrow down your field and sub-field of interest.** One cannot possibly work on “ecology,” but at most on a particular area in the (still fairly wide) field of evolutionary ecology, and in particular on the sub-field of the evolution of tradeoffs (or something like that). This choice should ideally be made between the last year as an undergraduate and the summer before enrolling as a PhD student. As with step I, the keys are going to be wide and extensive readings, and some experience as an apprentice (which may help as much to determine what one does not want to work on as what one is interested in).

**Step III -- Pick a good graduate program, but especially a good advisor.** Contrary to what most students seem to think, a good advisor (better if well-known in the field, or young and enthusiastic -- or better yet, all of the above) is much more important than a well known school or department. Of course, the latter qualities are also not to be underestimated, but you’ll have to work primarily with your advisor -- and s/he will have to write your most important letter of recommendation.

Depending on your characteristic, you may work better with some kinds of people rather than others. For example, if you need quite a bit of supervision you’ll be better off with an advisor who abitually looks over her students’ shoulders, at least in the beginning; but if you tend to be more independent, you’ll need somebody with a looser advising style. Talk to former and current students of your potential advisor(s) to find out as much as you can ahead of time. If an advisor doesn’t seem to work well for you within the first year, don’t hesitate to change, possibly while maintaining a civil relationship with your former one.

**Step IV -- Come up with some good questions.** Of course, this is much easier said than done, but there are some characteristics that make some questions better than others, and there are some good strategies to follow in order to identify the most promising questions within your sub-field of interest. First off (and once again), you can’t think on empty mind: read as much as you can, but this time focusing on the primary literature from the top journals in your field (which your advisor should have no difficulty in pointing out to you; examples may include Evolution, Ecology, The American Naturalist, etc.). Make also use of the now widespread publications that regularly update and summarize specific fields of inquiry (e.g., Trends in Ecology & Evolution, Trends in Genetics, BioEssays, and so forth).

What makes a question “good”? Several things: (a) It needs to be specific enough that one can work on it for 3-4 years and get publishable results, so things like “how did life on earth originate?” are out (though smaller components of the same inquiry might work). (b) On the other hand, you do wish to pursue
something that is of rather general interest in your broader field, which means that “what is the phylogenetic position of species X within genus Y?” may be a bit too narrow a choice (unless species X happens to be something like, say, *Homo sapiens*...). (c) A good PhD question (or, better, set of questions) also needs to be one which is going to generate good-level publications *regardless* of the particular answer you will arrive at by the end of your project; that’s what makes a dissertation on the search for extraterrestrial intelligence a rather poor choice: if you succeed you’ll probably get the Nobel, but the chances are much, much higher that you’ll obtain a bunch of negative results, which are notoriously difficult to get published. (d) It also helps, though it isn’t crucial, if the question(s) you are going to pursue can suitably be approached from more than one angle, or subdivided into smaller components; the goal should be to publish a minimum of three or four good-to-high level papers (possibly, some of them *before* you finish your PhD (to prepare you for the next step in the job market). While the often-heard “publish or perish” dictum in academia is a bit of an exaggeration, you will not get a job with few or low-level publications.

*Step V -- Choose a suitable experimental system.* This is almost as crucial a decision as the previous one, and it is well worth to take your time and “shop around” for a suitable system (animal, plant, or whatever) to work on -- *given your chosen questions and sub-field of interest.* Under no circumstances pick a system because it is “cute” or “cool,” and even established (“model”) systems may not represent the best choice for your particular needs.

Talk to people in your department, chat with your advisor, read around, and don’t hesitate to email people at other universities to seek more information about potential candidate systems. I cannot emphasize this enough: make the wrong choice at this stage and your entire academic career may well be headed for the drain before it even commences.

*Step VI -- Don’t be afraid to make adjustments.* Contrary to the impression one may receive from a naive reading of published technical papers, science doesn’t proceed in a straight line from question to experiment to results. It is a tortuous, and in some way much more fascinating, path -- more similar to the investigation of a crime than to the solution of a logical puzzle by way of deductive reasoning.

What this means is that you should not be afraid of playing with your questions and experimental system until the two shape each other in a satisfactory fashion. You are likely to end up with slightly (or sometimes dramatically) different questions than you started with, but one of the crucial characteristics of a good scientific investigator is the ability to follow her nose and seize the opportunities that serendipity lays out.

Of course, even if you follow the above steps very closely, your dissertation project may still not work in the end. That may be because you were not lucky (plenty of accidents can ruin an experiment or a field season), or perhaps because this isn’t your cup of tea after all. That’s a judgment call you’ll have to make on your own.

**Recommended readings:**


*Text by Massimo Pigliucci, available at www.genotypebyenvironment.org*
Four golden lessons

When I received my undergraduate degree — about a hundred years ago — the physics literature seemed to me a vast, unexplored ocean, every part of which I had to chart before beginning any research of my own. How could I do anything without knowing everything that had already been done? Fortunately, in my first year of graduate school, I had the good luck to fall into the hands of senior physicists who insisted, over my anxious objections, that I must start doing research, and pick up what I needed to know as I went along. It was sink or swim. To my surprise, I found that this worked. I managed to get a quick PhD — though when I got it I knew almost nothing about physics. But I did learn one big thing: that no one knows everything, and you don’t have to.

Another lesson to be learned, to continue using my oceanographic metaphor, is that while you are swimming and not sinking you should aim for rough water. When I was teaching at the Massachusetts Institute of Technology in the late 1960s, a student told me that he wanted to go into general relativity rather than the area I was working on, elementary particle physics, because the principles of the former were well known, while the latter seemed like a mess to him. It struck me that he had just given a perfectly good reason for doing the opposite. Particle physics was an area where creative work could still be done. It really was a mess in the 1960s, but since that time the work of many theoretical and experimental physicists has been able to sort it out, and put everything (well, almost everything) together in a beautiful theory known as the standard model. My advice is to go for the messes — that’s where the action is.

My third piece of advice is probably the hardest to take. It is to forgive yourself for wasting time. Students are only asked to solve problems that their professors (unless unusually cruel) know to be solvable. In addition, it doesn’t matter if the problems are scientifically important — they have to be solved to pass the course. But in the real world, it’s very hard to know which problems are important, and you never know whether at a given moment in history a problem is solvable. At the beginning of the twentieth century, several leading physicists, including Lorentz and Abraham, were trying to work out a theory of the electron. This was partly in order to understand why all attempts to detect effects of Earth’s motion through the ether had failed. We now know that they were working on the wrong problem. At that time, no one could have developed a successful theory of the electron, because quantum mechanics had not yet been discovered. It took the genius of Albert Einstein in 1905 to realize that the right problem on which to work was the effect of motion on measurements of space and time. This led him to the special theory of relativity. As you will never be sure which are the right problems to work on, most of the time that you spend in the laboratory or at your desk will be wasted. If you want to be creative, then you will have to get used to spending most of your time not being creative, to being becalmed on the ocean of scientific knowledge.

Finally, learn something about the history of science, or at a minimum the history of your own branch of science. The least important reason for this is that the history may actually be of some use to you in your own scientific work. For instance, now and then scientists are hampered by believing one of the over-simplified models of science that have been proposed by philosophers from Francis Bacon to Thomas Kuhn and Karl Popper. The best antidote to the philosophy of science is a knowledge of the history of science.

More importantly, the history of science can make work seem more worthwhile to you. As a scientist, you’re probably not going to get rich. Your friends and relatives probably won’t understand what you’re doing. And if you work in a field like elementary particle physics, you won’t even have the satisfaction of doing something that is immediately useful. But you can get great satisfaction by recognizing that your work in science is a part of history.

Look back 100 years, to 1903. How important is it now who was Prime Minister of Great Britain in 1903, or President of the United States? What stands out as really important is that at McGill University, Ernest Rutherford and Frederick Soddy were working out the nature of radioactivity. This work (of course!) had practical applications, but much more important were its cultural implications. The understanding of radioactivity allowed physicists to explain how the Sun and Earth’s cores could still be hot after millions of years. In this way, it removed the last scientific objection to what many geologists and paleontologists thought was the great age of the Earth and the Sun. After this, Christians and Jews either had to give up belief in the literal truth of the Bible or resign themselves to intellectual irrelevance. This was just one step in a sequence of steps from Galileo through Newton and Darwin to the present that, time after time, has weakened the hold of religious dogmatism. Reading any newspaper nowadays is enough to show you that this work is not yet complete. But it is civilizing work, of which scientists are able to feel proud.

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Editorial—A plea for scholarly writing

Scientific writing is a skill that needs to be developed through concentration and practice. By the final draft of a paper, each sentence should have been crafted to convey information clearly, succinctly, and accurately. The standard of writing in current scientific journals has reached an all-time low, in terms of both poor grammar and imprecise communication. This situation has been fueled on one hand by escalating costs of publication and an attempt to shorten papers and, on the other hand, by inadequate training in the structure of the English language.

Changes in the English language

The English language, being a composite of Anglo-Saxon languages and French, is one of the most expressive languages of the world. Many words of Anglo-Saxon origin have a counterpart of French origin. These paired words are not exact synonyms but rather, over the years, have come to express slight nuances of meaning that give to English an unusual precision and richness. Not only has English changed in the above way but also multiple spellings for particular words were reduced to a single, accepted spelling, rules for punctuation that reduced ambiguity were established, and guidelines for grammar and the structuring of sentences came into play. The preparation for the first edition of the Oxford English Dictionary began in 1857 and reached fruition 70 years later after tens of thousands of participants contributed to the organization of 414,825 precise definitions under the editorship of Professor James Murray (Winchester 1998). This dictionary was a milestone in the development of the English language and it became the official standard.

These improvements have been largely ignored in recent elementary and secondary education in the United States and few young Americans understand the structure or usage of their own language, a misfortune that becomes painfully obvious to most teaching faculty on a daily basis. It is paradoxical that many educated foreigners have a better grasp of the structure and grammar of English than do many Americans whose native language is English. How often does one wince at the grammatical errors made by announcers of news on television or at the linguistic atrocities committed in newspaper articles?

As deplorable as is the degradation of English within the populace at large, it has not sunk to the depth plumbed by scientific writing. The refinement of English over the centuries has been fractured by a generation of scientists who supposedly are dedicated to precise thinking and accurate methodology. It is unfortunate that such pinnacles of thought and achievement have been nullified by ambiguous, slovenly communication. At one time, a tertiary teacher could inspire students to achieve a better standard of scientific expression by referring them to current issues of a journal in their field of specialty. Now, many of those articles are best described, not as examples of good scientific writing, but as examples of how one should NOT write scientific papers. In a recent assessment of one of the most prestigious journals published in the United States, I examined the titles of the articles in the issues from the past 5 years. Most contained grammatical errors. Many of the articles, although deserving an “A” for scientific content, scarcely merited a “C-” were the article to be submitted as a composition for a high school class in English.

An important principle in scientific (and other) writing is that the language should convey precise meaning without recourse to other sources of interpretation. A sentence should say what it means, not provide a clue to a possible meaning that must be gleaned from context. The meaning should be unambiguous. The blatant disregard for the rules of the English language inherent in much scientific writing violates this principle.

Below are listed some of the common mistakes that are made in scientific writing, accompanied by examples taken from papers either published in, or submitted to, prestigious, peer-reviewed scientific journal or books. In some cases, names of persons or species were changed to preserve anonymity of authorship.

Excessive use of nouns as adjectives

The most glaring abuse of English in scientific writing is an excessive use of nouns as adjectives,
especially by stringing a number of them together (called freight-training). Not only is it difficult to decipher which noun modifies which other, but also the flow of language is interrupted because of the necessity to pause and interpret the meaning. When my graduate students begin writing their dissertations, I challenge them to note examples of freight-training in their reading and write down the various meanings that could be construed from confusing passages. This exercise often leads to a more thoughtful use of language on their part, makes my reading of theses less laborious, and promotes conservation of red pencils.

A few examples from articles published in prestigious scientific journals may illustrate the ambiguity arising from the use of nouns as adjectives:

"Post-hurricane canopy lizard study methods are provided…"

Try to figure that out. I think it means the methods used in a study of lizards that inhabit canopies that was carried out after a hurricane.

"A model incorporating individual learning rules and migration costs into a many-patch ideal free distribution examines how the spatial distribution of predators and prey mortality are affected." As it stands, this sentence is unintelligible. Does the first part mean: (1) "individual learning rules" and "individual learning migration costs"? (whatever that might be), (2) "individual learning rules" and "individual migration costs"? or (3) "migration costs" and "individual learning rules"? There is no way to decide from the language used. If you already know what the author means, or can get it from context, it may be possible to understand this part of the sentence. A simple way to resolve the ambiguity of this phrase is to reverse the order to read: "A model incorporating migration costs and individual learning rules for learning into a …" (from context I think that is what the author was trying to say). The second part of the sentence is even worse. Does it mean: (1) a distribution that is free of many-patch ideals? (2) a free distribution somehow involving a many-patch ideal? or (3) nothing at all?

The sentence just discussed was taken from the abstract. It foreshadowed what was to come. The body of the paper was loaded with similar inad-equacies. For example: "However, the links between learning as studied by behavioral ecologists working on foraging and mainstream animal learning…" Is the author writing about mainstream animals or mainstream learning of animals, or the foraging and learning of mainstream animals, or what? A later sentence reads: "Foraging theorists became interested in learning for two reasons…" From context it seems likely that the author does not really mean that theorists that were foraging became interested in learning. (I can see it now: There I was, foraging in the refrigerator for a sandwich when I suddenly became interested in learning.) He is trying to say that persons who theorize about foraging became interested in learning.

"In addition, captive breeding programs could be established to supply the small private keeper demand for snakes…” Is this a breeding program that is captive or a program of captive breeding? Neither makes very much sense if taken literally. The second part seems to mean either that the demand is by private keepers that are small, or that there is a small demand from private keepers. However, neither is correct. From context, it appears to mean that the demand is by keepers of private collections that are small!

"Species abundance distribution patterns of microarthropods in surface decomposing leaf-litter and mineral soil on a desert watershed…” Note that there are six nouns and a gerund used as adjectives. Three modify "patterns" and two modify "leaf-litter" and the rest are singles. That does not include two compound words (microarthropods and watershed) and one hyphenated one, all of which have built-in modifiers.

"It was found that larval ingestion rates were higher…” Does this mean that larvae were ingesting something at a higher rate, or that something was ingesting larvae at a higher rate? It is not clear from the statement itself although one could make a reasonable guess by examining the context. If the former meaning is intended, it could be clarified by the statement: "It was found that the rates at which larvae ingested were higher…” and if the latter, by the statement: "It was found that the rate at which larvae were ingested was higher…” The original statement used nine words (44 characters), the first clarification used 12 words (53 characters), and the second clarification used 13 words (55 characters). Is this too high a price for moving from ambiguity to clarity?

"If nutrient fertilization also increases the likelihood and the severity of key plant diseases, then determining the optimal fertilizer application level can become complex.” How does one fertilize nutrients?”

"Dog feeding mechanisms are well studied.” This does not mean mechanisms for feeding something to dogs or of feeding dogs to something but (from context) rather the mechanisms dogs use in feeding. In this case hyphens could be used for clarification. “dog-feeding mechanisms” are quite different from
“dog feeding-mechanisms.” The latter should really be “dogs’ feeding mechanisms.”

“Digital data sampling” Again, hyphens can come to the rescue. “digital-data sampling” is not the same as “digital data-sampling.”

In general, compound adjectives can be hyphenated to link the two modifiers. Take the words “life history” for example. When not used to modify another word these two words are not hyphenated, as in the sentence: “The life history of the frog is interesting.” When they are used as an adjective they should be hyphenated as in the sentence: “The life-history strategy of the frog is interesting.” Clarity can be added to a manuscript by going through it and identifying compound adjectives and hyphenating them. Much of the ambiguity of freight-training can be avoided in this way.

Perhaps the most common, and most humorous misuse of adjectives refers to gender. In the English language, data do not have gender. One commonly encounters references to “male data” and “female data.” Perhaps this is why male data are put in separate columns from female data; otherwise “juvenile” data might be generated that would clutter the paper! Of course, the intended meaning is: “data from males” and “data from females.”

I leave it to the reader to ponder the meaning of the following: “hatching enzymes,” “malformed frog investigation,” “field site velocities.”

**Verbosity**

Use of unnecessary words or complicated phraseology does not make a paper appear more scholarly; indeed, just the opposite is true. A series of long words should not be used if a few, shorter ones convey the meaning better. An excerpt from a recent scientific paper illustrates this point: “….enhance your knowledge base of….” really means “….inform you about….”

**Ambiguous wording**

“The evolution of locomotion during prey capture.” This must be very rapid evolution—but is it the locomotion of the predator or the locomotion of the prey that evolves at such a great speed? Probably the intended meaning is: “the evolution of locomotion involved in the capture of prey.”

“This species is another frog reported as potentially threatened by Smith (2006).” It sounds as though Smith is threatening the frog! It should read: This species is another frog reported by Smith (2006) as potentially threatened.

“There was strong evidence of activation that had been inferred in previous beetle reports.” This sound like beetles wrote the report. The phrase should be “reports about beetles.”

“Behavior in small bird flocks, medium bird flocks and large bird flocks…” leaves one wondering whether birds or flocks are of different sizes. One cannot tell from the wording of the sentence. Hyphens would help. If the birds are of different sizes, then “small-bird flocks, medium-bird flocks, and large-bird flocks” would make sense. If it is the size of the flocks that varies, then “small bird-flocks, medium bird-flocks, and large bird-flocks” would indicate that. Still better would be a complete revising of the sentence to read either “Behavior of birds in small, medium-sized, and large flocks” if that were the intended meaning, or “Behavior of small birds, medium-sized birds, and large birds in flocks…” were the alternate interpretation intended.

One who can’t distinguish between extra-marital sex and extra marital sex is likely to become acutely aware of the importance of hyphenation!

“….on the basis of research on largely human subjects…” surely was intended to mean “ largely on the basis of research on humans.” Are you largely human?

**Poor punctuation**

Older books on grammar indicated that commas should set off all parts of a series. More recently, the tendency is to allow dropping the last comma of a series (known as the Oxford comma or serial comma) (Truss 2006), thereby leading to ambiguity. Indeed, this alternative is now often deemed to be the “correct” one and the older standard to be incorrect.

Consider the following example: “As more information on the actual geographic pattern of pesticide residues becomes available, it will be possible to test the association between pesticide uses, predominate winds, and residues that are assumed in the previous study.” Use of a comma after “winds” indicates that there are predominate winds and there are residues (the correct meaning).

Now examine the paragraph without the Oxford comma: “As more information on the actual geographic pattern of pesticide residues becomes available, it will be possible to test the association between pesticide uses, predominate winds and residues that are assumed in the previous study.” Absence of the Oxford comma indicates that there are predominate winds and there also are predominate residues (an incorrect meaning). Ambiguity frequently arises when the comma is omitted before
the last of a series and in such cases the Oxford comma should be used. I suggest that for the sake of consistency it should always be used.

The importance of correct punctuation can be illustrated by the oft-cited anecdote about a teacher’s response to a principal who told students that studying punctuation was a waste of time. The teacher went to the blackboard and wrote: “The principal said the teacher is wrong.” The principal smiled approvingly, whereupon the teacher punctuated the sentence as: “The principal, said the teacher, is wrong.” The smile left his face.


Plurality of the word “data”
The word “data” is a plural noun. The singular is “datum.” Hence, the proper usage is “data are” not “data is.” Similarly, one should say “these data” not “this data.” I have to correct such errors repeatedly in almost every article I edit, even those written by senior scientists. Recently, at an otherwise excellent symposium, every presenter that used the word “data” did so incorrectly. I did not notice many people wincing. In business and law it has become commonplace to use “data” as a singular noun but that should not give scientists license to be equally slovenly.

More or Less
The word “more” has two opposites. “Less” is the correct choice when dealing with amounts, and “few” should be used when dealing with numbers. It is incorrect to say “less animals” instead of “fewer animals.”

Which or that?
Another common pitfall is the incorrect use of “which” for “that.” Consult a good style manual for correct usage of these two words.

Do, did, and in (uncertain objects of verbs)
A recent example of an uncertain object of a verb is: “Males consumed more prey than females.” This implies that males consumed females to a greater extent than males consumed prey. In fact, from context, males did not eat any females at all but rather the comparison was between males and females in the amount eaten. The sentence should read: “Males consumed more prey than did females. This kind of error is common in scientific writing. Use of “did” or “do” (“Males consume more prey than do females”) can clarify these ambiguities.

“The effect of such strong temporal decline in calcium is most severe in species breeding in seasonal ponds or small streams…” suggests that ponds and small streams are both seasonal, something that, from context, was not true. This ambiguity can be eliminated by use of the word “in,” as in “breeding in seasonal ponds or in small streams.”

Reviewed in Smith and Jones (2008)
If taken literally, a citation in this form is absurd; presumably it stands for “reviewed in the paper by Smith and Jones.” Why not merely write: “reviewed by Smith and Jones,” an accurate statement that is just as short as the original incorrect one.

Redundancy
There are common redundancies that are frequently found in scientific writing. Note that the previous sentence has a redundancy: common versus frequently. No meaning is lost by shortening this sentence either to: “There are common redundancies found in scientific writing.” or better still: “There are redundancies that are frequently found in scientific writing.”

A common redundancy is: “point in time” when merely “time” would suffice. Another is: “revert back.” The single word “revert” is sufficient.

Temperature
One frequently finds references to “hot temperatures” or statements that temperatures at one site were “cooler” than at another. Temperatures are neither hot nor cold. Objects are hot or cold; temperatures are high or low.

What generates such fracturing of the English language?
Other than the abandonment of teaching English rigorously in children’s early education, the main reason for recent degradation in communication by scientists seems to be the cost of publication. Most journals have financial strictures and need to conserve funds. Accordingly, authors are under pressure to condense their manuscripts as much as possible and delete all extraneous material. A common instruction to a potential author from the editor and reviewers is to explain topics A, B, and C in more detail, clarify why technique E was used, and
so on, all of which demands use of more space. These instructions are commonly followed by a demand to reduce the length of the paper by 20%. The only way an author can comply is to use “compact,” “condensed,” or “direct” style, a euphemism for a telegraphic, grammatically incorrect, confusing, and ambiguous obfuscation, i.e., modern scientific writing. At first, authors abhorred this style of writing but it has become so habitual that to many it now appears correct, and may even be preferred. It recalls a phenomenon I have experienced in reading manuscripts. After reading a thesis in which a particular, common word was consistently misspelled, by the end of the article the incorrect spelling had become familiar and the correct usage began to appear strange. I have lost several words by this process; at one time I could spell them but now I have to look them up!

Many incorrect uses have become so ritualized in particular disciplines that they now constitute a code that is understood by all practitioners of that field (but not to outsiders). Attempts to correct these and put them into English that is understandable by scientists in other specialties engenders objections on the ground that “this is the way it is written in my particular field.” The question is not whether it is written that way, but whether it should be written that way. Is it not just as undesirable to produce bad writing as it is to produce bad science? The adherence to codified, nonsensical expressions is one reason scientists are having increasing difficulty in communicating their findings to the public at large. If one has to codify technical terms, then it should be done in a grammatically correct manner. This can be achieved by the judicious use of hyphens (see examples above), or it could be achieved by adopting the practice in Germanic languages of making a new word by merely combining two others such that the new one has a specific, unambiguous meaning, separate from its components. The word “dataset” is in common usage. Perhaps many more such words, either hyphenated or directly combined, should be coined, rather than using two words that, although accepted by the practitioners of the discipline, lack clarity.

I suggest that we have gone too far in reducing publication costs. Quality is expensive. Is it worthwhile to condense a paper to the extent that the meaning is not clear, or the language absurd? It may be better to publish fewer papers, but insist on a higher standard of language as well as of scholarship. If a paper is scarcely understandable by a native English speaker, think how confusing it would be to someone for whom English is a second language (but see above).

The editorial policy of ICB is to produce a scholarly journal of high quality, both in science and in writing. Authors are encouraged, once their manuscript is deemed to be ready for submission, to go over it one more time and make sure each sentence conveys precise, grammatically correct, unambiguous meaning.

Lest the reader consider this brief note an example of editorial arrogance, I should acknowledge that even in the last draft I found myself guilty of some of the sins against which I have railed. If any corruptions of the language remain, the reader is entitled to gleefully gloat upon them.

**References**


*Harold Heatwole, Editor, ICB*
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<tr>
<th>Checklist Item</th>
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<tbody>
<tr>
<td>Did I talk to my Advisor within the last week?</td>
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<tr>
<td>There are no weekends in graduate school</td>
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<tr>
<td>Money? I don’t think about such irrelevancies</td>
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<td>A paper a day keeps the Advisor away</td>
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<td>Data, data, do I have enough data?</td>
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<td>To prioritize, you need to know your goals</td>
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<td>Did I hug my organism today?</td>
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<td>Does the Biology Librarian know my name?</td>
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