How to Survive, Thrive, and Learn Science in Graduate School: One Student’s Perspective

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ABSTRACT

Many people enter scientific careers by way of graduate school. Some aspects of success in graduate school depend on informal sharing of knowledge that occurs among students. To formalize some of the student-to-student teaching, I have articulated eight practical ideas based on my experience about how students can perform well and develop habits in graduate school that will lead to being able to do good science in the future. These ideas are arranged under the major principles of motivation, discipline, and knowledge. Students should: work with others, work on something they believe in, meet their advisors regularly, plan experiments carefully, be meticulous in their work, not procrastinate, understand statistics applicable to their work, and have a good grounding in the basic sciences. Examples of well-known scientists who followed these practices are included.

I completed an M.S. degree in agronomy in 1993, joined the work force for several years, and completed a Ph.D. degree in soil science in 2003. This article reflects what I learned through my own experiences—not about soil science, but about doing research in pursuit of a graduate degree. This article describes what I wish I had known about research from the beginning of graduate school. Because this is what “everybody knows,” no one tells new students. I hope to spare you, my fellow students, some pain. My advice is primarily directed toward students in the natural sciences who are committed to their work, need help. Furthermore, collaboration and cooperation is emotional support (Carter and Highfield, 1994). Even he shared his work with her and she probably contributed significantly to the development of his ideas. Throughout his life, he sought colleagues and personal friends for intellectual and emotional support (Carter and Highfield, 1994). Even he needed help. Furthermore, collaboration and cooperation is imperative in science. If James Watson and Francis Crick had not worked together, Rosalind Franklin’s group might have won the race to elucidate the structure of DNA (Watson, 1968; Sayre, 1975).

Idea 1

Work on a team project. My project was of great interest to me, but was unrelated to the work of other people in my advisor’s lab; it was difficult for me to sustain enthusiasm and display stamina while working basically alone. Other people provide extrinsic motivation, impetus that comes from their energy and excitement. In a team project all the work contributes to the common goal, so asking for help, returning help, discussing ideas, and solving problems are much easier because of the collaborative effort. If you cannot work on a team project, find people who are interested in your work and with whom frequent interaction is possible.

Some scientists can seemingly work alone and make brilliant progress. Albert Einstein’s revolutionary work in relativity was apparently done in splendid isolation as he clerked in a patent office. This popular story is not accurate. Dr. Einstein’s fiancée, who became his wife before he published his important papers, was the mathematician Mileva Maric. He shared his work with her and she probably contributed significantly to the development of his ideas. Throughout his life, he sought colleagues and personal friends for intellectual and emotional support (Carter and Highfield, 1994). Even he needed help. Furthermore, collaboration and cooperation is imperative in science. If James Watson and Francis Crick had not worked together, Rosalind Franklin’s group might have won the race to elucidate the structure of DNA (Watson, 1968; Sayre, 1975).

Idea 2

Work on something personally important. Intrinsic motivation, or impetus arising from private commitment, is necessary because acquiring the discipline to become and remain a scientist is almost impossible without it. Although I wanted to give up when the work was hard, my dissertation topic fascinated me enough that I continued. The naturalist John Janovy, Varner Professor of Biological Sciences at the University of Nebraska-Lincoln, says, “Without desire, sustained effort is impossible…we begin to get a clue as to what motivates satisfied biologists. They love what they are doing” (Janovy, 1985, p. 41).

Jane Goodall is such a famous scientist in part because she believes in her work. From the beginning, she knew that chimpanzees were important enough to her to spend days and years studying them and becoming their advocate. She said, “…we do not need to justify, in terms of relevance to ourselves,
the study of a creature who is surely, next to Homo sapiens, the most fascinating and complex in the world today” (Goodall, 1986, p. 4). Chimpanzees did not need to be “useful.” It was enough for her that she was interested in them. However, Dr. Goodall needed help. Dr. Louis Leakey mentored her, and her mother accompanied her to Tanzania during her first field excursion as a very young scientist (Goodall and Berman, 2000).

I certainly do not intend to compare myself to Jane Goodall, but my experience has corroborated hers: I know the power of the combination of inner passion plus support from interested colleagues.

Idea 3

Stay in touch with your advisor. Mentoring from a good advisor can help you to get the most out of a graduate degree, and to finish the degree in a reasonable time frame. Expert guidance can prevent you from making mistakes such as performing unnecessary or poorly designed experiments.

You may work more efficiently and diligently to meet your advisor’s expectations than your own (Conti, 2000), an example of extrinsic motivation. Martin Schwarzschild, winner of the 1965 Bruce Medal for lifetime achievement in the astrophysical sciences, used to require weekly meetings with his students (personal communication, S. Bhavsar, 2003).

Because my project was not closely related to my advisor’s other projects, I had to seek him out, something I did not do enough, although he gave generously of his time when I went to him. But even when your advisor maintains a constant presence in the lab or the field, try to get regular meetings with him or her so that attention can be concentrated on your project. Most advisors appreciate students who take initiative and ask for meetings. If your advisor is unwilling or consistently unable to spend time with a well-prepared, hardworking, motivated student, consider changing advisors.

Meeting once a week as Dr. Schwarzschild required might be too often, but once a month might be too rare; you and your advisor should decide together. A good format is for you, the student, to prepare a 1- or 2-page summary of notes, results, questions, ideas, plans, and so forth, and let your advisor read it at the beginning of the meeting. Not only do you have a chance to review and learn from your work, substantial discussion is assured this way. Keep careful notes during these meetings, so you will remember the ideas your advisor gives. If meetings are regular and discussion is significant, each meeting should not need to be long or burdensome. Of course, you should make progress between meetings. If your advisor suggests an activity, do it, and be ready to discuss it next time.

Discipline

The quotation “Genius is 1% inspiration, 99% perspiration” is famously attributed to Thomas Edison (Harper’s, New York September 1932). Unfortunately, talent in science is not enough; every student must develop some skills and habits through tedious practice.

Idea 4

Plan carefully. A well-designed, carefully conceived experiment is much more likely to achieve defensible, worthwhile results than one based on a half-formed idea. “There can be no greater waste of time and money than to embark on….applied research before one has a clear idea of the precise course of action….before, and I emphasize ‘before,’ a single piece of data has been collected” (Wilson, 1974, p. 20). I have interviewed the scientists in charge of three large, long-term agricultural systems projects in different parts of the USA, and all of them agree that planning was the most important step in performing the research (personal communications, V.G. Allen, N. Creamer, P. Mueller, and S. Kaffka, 2004). Peter Johnstone’s book titled Planning and Managing Agricultural and Ecological Experiments (Johnstone, 1998) is a good guide to planning and completing experiments. The book is short and simple enough to read all the way through.

If an overall project has smaller parts, make a whole plan and then plan each part with attention paid to the contribution of the smaller project to the overall plan. Read the literature, draft and revise plans multiple times, and talk often to your advisor in this stage.

Written, detailed protocols should be generated for every experiment, however small. As the experiment progresses, things will probably need to change, but having an initial plan ensures that changes are thoughtful, not reactionary. Having plans also facilitates correct data interpretation. Sir Alexander Fleming found his penicillin-containing plate unexpectedly, but his whole laboratory was dedicated to the search for antibiotic organisms (Maurois, 1959). He knew what he had because he was looking for it.

Idea 5

Meticulous work is essential. Louis Pasteur, one of the most important biologists of all time and a pioneer of experimental technique, said, “Imagination should give wings to our thoughts, but we always need decisive experimental proof, and when the moment comes to draw conclusions and to interpret the gathered observations, imagination must be checked and documented by the factual results of the experiment” (Rhee, 1999). Getting decisive experimental proof requires careful work, to which there are several aspects.

First, keep excellent records and notes, including pictures when appropriate. Records about what happened in an experiment are essential for interpreting results. Notes contribute to procedural repeatability and can identify procedural problems, which strengthens results by reducing variation. Do not trust your memory, however hard it is to write extensive notes about every activity. At the very least, have a journal where activities are logged for each experiment, plus calculations, conversion factors, and so forth. Describe problems, environmental conditions, deviations from procedure, and anything else unusual. Use the observations and notes as adjuncts to your data. Be as neat and organized as possible, because you will have to re-visit these records more than once. I have a different loose-leaf notebook for every experiment where I keep data sheets, printouts, descriptions of methods, and all my notes for that experiment.

Second, label all samples fully and carefully. Of course I knew to do this before embarking on my Ph.D. research, but I re-learned the hard way at least once by having to discard “mystery bottles.” Create a labeling system that includes, at minimum: the date samples were taken, the site they are from,
what they are or what analysis should be done, the experimental treatment description, and the replication. Number the samples and keep a record of which number corresponds to treatments and replications. It is best to maintain consistent labeling patterns throughout an experiment. For samples that will be completely analyzed and the data captured within a few hours, the sample number may be used alone. In data files, use all information contained in the sample label.

Third, document your data in detail and keep it organized, both on paper and electronically. Most projects generate a great deal of data and many, many computer files in various stages of development. Label and describe files so that you know immediately what information they contain and how old the information is. For example, make notes at the top of each spreadsheet explaining column headings or other internal shortcuts. Record when a file is updated; do not depend entirely on the computer to date files. Keep strict track of data sheets. Back up all computer files and make copies of all paper data. Nothing is more discouraging in research than working very hard to get data and then losing that data through careless archiving. Serious recordkeeping and labeling is daunting and laborious at first. Stay with it; you will get used to it and develop helpful shortcuts.

Fourth, be patient and exacting in lab work. For example, if old standards or reagents are questionable, make new ones. For another example, make sure that glassware is properly cleaned for your purposes. Time spent being careful can save you from wasting hours trying to find and fix problems. Experience will show you legitimate shortcuts and you will get faster with practice. Most importantly, do not neglect safety! A trip to the emergency room takes hours, as I have the scar to prove.

Fifth, practice ahead of time and set up pilot projects. I learned the value of pilot projects the very hard way by setting up an experiment with more than 500 samples and processing all of them (i) before I knew if my design would give me the answers I sought, and (ii) before I had mastered my lab techniques, which gave me a lot of experimental error. If I had set up a much smaller test experiment, I would have seen that most of my work was not necessary, and the required work would have been performed more professionally. This story is quite embarrassing, so please repay me for telling it by profiting from my mistake.

Dry runs, pilot projects, test plots, and so forth seem like a waste of time to a student in a hurry to complete a degree. But test runs and pilot projects save time in the end. Potential problems are identified and preliminary data are available to refine hypotheses. Gain the habit in graduate school of processing all of them (i) before I knew if my design would give me the answers I sought, and (ii) before I had mastered my lab techniques, which gave me a lot of experimental error. If I had set up a much smaller test experiment, I would have seen that most of my work was not necessary, and the required work would have been performed more professionally. This story is quite embarrassing, so please repay me for telling it by profiting from my mistake.

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Do not procrastinate. Deal with samples, data, literature, and other work promptly. Procrastination is a plague of academic life and has behavioral, cognitive, and emotional roots. Fear, laziness, perfectionism, frustration, anger, and anticipation of a job being difficult are common reasons for procrastination (Ferrari et al., 1995). I have experienced most of them, and I conclude that the pain of hard work is far less than the pain of anticipation.

Regular meetings with your advisor will help to rein in procrastination by providing extrinsic motivation (Conti, 2000) and easing fears or finding answers to problems. Find ways to make work pleasant so you will look forward to it (Sigall et al., 2000); I like listening to audio books while doing lab work that does not need strict attention. Discipline yourself to work and use every possible means to avoid procrastination, including counseling if procrastination is a serious problem for you.

Knowledge

My personal observation is that students know soil science, plant science, forestry, or animal science, but the basics behind those sciences are often assumed. Much research reaches stronger conclusions if the theoretical basis of the work is sound. Furthermore, one goal for most graduate programs is for a student to develop the ability to create projects that reach beyond the empirical. Understanding the basic sciences can be very helpful in designing, implementing, and interpreting sound research projects.

Idea 7

Understand your own statistical analysis. The definition of statistics is “a branch of mathematics dealing with the collection, analysis, interpretation, and presentation of masses of numerical data” (Merriam-Webster, 2004). Most research involves large masses of numerical data. If you understand why a particular statistical analysis is appropriate and what the analysis means, you will understand your own data and make correct interpretations.

Many people find statistics difficult and even intimidating (Onwuegbuzie and Wilson, 2003). The better you understand the analyses you will use, the less threatening statistics become. Also, it is easier and more elegant to design an experiment intentionally than to find a design to fit a completed experiment. Well before beginning an experiment, find a person who can guide you in deciding on appropriate statistical designs to address your experimental question. Make sure you understand the statistical tests possible for your design. When data are available, learn to describe how each statistical test leads to your interpretation of results.

Your advisor and committee members should be able to help you with statistics, but do not rely entirely on them. Every scientist develops some favorite experimental designs, which can limit a student. Also, although an a priori experimental design is critical, many experiments can be analyzed in more than one way. With today’s software, manipulating data and trying different methods is easy. However, do not fall into the trap of using a particular statistical method just because the software is available.

To repeat a previous piece of advice, do not procrastinate in analyzing data because of fear of statistics or imperfect results (which are quite likely). As soon as data are available,
perform basic statistical analyses and try to make interpretations. These results will guide your next steps. Again, keep in touch with your advisor as results are available.

Idea 8

Have a grounding in basic biology, chemistry, physics, and math. If you are already in graduate school it may be difficult to pick up such classes. If possible, try. Choose what is necessary for your field; biochemistry might be more important than inorganic chemistry, for example. Chemistry and physics, in particular, require practice. I attended a soil chemistry seminar near the end of my Ph.D. program and was uncomfortable because I did not follow much of the presentation—until I looked around and realized that I was not alone. Everyone in the audience had almost certainly had experience in chemistry, but few people had enough active knowledge to ask intelligent questions.

Linus Pauling, the only winner of two individually awarded Nobel prizes, was a legendary scientist, teacher, and peace activist. His vast understanding of basic sciences allowed him to span topics from X-ray crystallography to sickle-cell anemia to vitamin C, and to make educated guesses that were far more often right than wrong. He thought that scientists have more fun than anyone else (Soka Gakkai Int., 2004), and he may well have had more fun than most. He thought that scientists have more fun than anyone else (Soka Gakkai Int., 2004), and he may well have had more fun than most. If you have broad understanding of the basic natural laws behind your work, your work will be stronger and you will have a springboard to reach farther.

CONCLUSIONS

Becoming a scientist is not easy. Like other worthwhile human endeavors such as art, music, writing, family and community life, or any career, science requires its practitioners to learn some very difficult skills. Some of those skills include working with others and alone, following a mentor’s guidance, planning, meticulous experimental work, cultivating the discipline to overcome procrastination, and broadening one’s knowledge beyond the confines of a narrow research question. As can be seen from the stories of some of the best scientists, patience, humor, commitment, and even love of the work (Janovy, 1985) are necessary.

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REFERENCES


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Victoria Mundy Bhavsar has been involved with college teaching as a learner for more than 17 years, and off and on as a teacher for almost that long. During her postdoc, she very much enjoyed interacting with graduate students. She realized that many students made all the same mistakes she did. Reflecting on what she had learned about becoming a scientific practitioner and writing down her thoughts to benefit others seemed like a way to engage in a new kind of teaching. She hopes people find this paper useful, at least as a starting point for discussion with advisors or other students.