1 Introduction

You're planning to pursue graduate education or perhaps are in an early stage of graduate study in science or engineering, or perhaps the humanities. You might therefore be thinking that the future course of your graduate studies and career thereafter are well set in place: you can now proceed with your course work and research largely on automatic pilot. The experience of most graduate students, however, is unfortunately to the contrary. While you know not to expect smooth sailing in your studies and research, you might be unaware that many roadblocks, sources of frustration and angst, and much wasted time during and after graduate study can be avoided or at least substantially minimized, perhaps making the entire experience largely satisfying, indeed joyful – one in which you thrive.

This book is a practical guide with two primary goals. The first is to help make the experience of graduate study for students early in their graduate program in science, and for senior-level undergraduates intent on entering such a program, be an efficient, effective, and generally positive one. The second goal, consistent with the first, is to help those students and other junior researchers develop effective research habits.

While some will choose to read this book from cover to cover, many will find benefit from reading selected chapters in depth at different stages of their university or professional careers, perhaps returning to specific chapters as needed.

For three reasons, the contents of this book are not focused on the disciplinary aspects of research. First, one cannot hope to cover all research fields in a single book nor would the reader be drawn to the intricacies and subtleties in specific research areas across the breadth of scientific disciplines. Second, the authors of course do not have close to the necessary disciplinary expertise for the many different

fields in science. Third, it would defeat the purpose of the book, which aims to offer broad counsel for aspiring researchers, independent of discipline. The book therefore focuses on practical aspects of research that are of relevance for students and young researchers in the sciences in general. Throughout the book, we use the word *science*, but since many aspects of research are generic for both science and engineering, the guidance offered here should be of comparable relevance as well to engineers intent on a career in or closely related to research. Research approaches differ among various fields, but much of the presented material should also be of benefit in the graduate and early research careers of students in the humanities and medicine, as well.

It's a good bet that none of Isaac Newton, Francis Crick, nor Charles Darwin would have been interested in or had need for this book. They had an innate sense of how to blaze profound trails in science, driven by their curiosity and aided by clear focus of attention. The vast number of budding scientists at early stages of their graduate-school careers, however, could benefit from many of the suggestions in the book. Decades back, when we two authors were students, we would have done well to have such guidance.

Certainly Ph.D. and M.Sc. programs can be successfully completed without access to the suggestions offered in this book. Countless scientists have made it through graduate school without such guidance en route to their often outstanding careers, so the graduate experience can and does work. Ultimately getting to the stage of writing and defending the thesis undoubtedly constitutes one level of successful completion. A central tenet of this book, however, is that a more satisfying degree of success would be the defending of research that is an excellent fit for the candidate in the sense of its match for his or her talents and interests, and getting to that moment efficiently, with a minimum of time, pain, and consternation, and a maximum of enjoyment and professional success.

For any of a number of reasons, you have willingly chosen – likely been drawn to – a career in science, and this choice is one that you probably have made with some excitement. Many of you can be

said to love the ideas in science and technology that have attracted you. It is all the better therefore that your pursuit of science, from graduate school through your subsequent career, turns out to be a joyfully memorable experience.

Why this book? Unquestionably, the pursuit of a Ph.D. or Masters degree can be a challenge at times. Much needs to be learned along the way – about both the science and the scientific technique – and that learning takes time, discipline, and hard work. The suggestions offered in this book won't remove that essential challenge. Rather, what they aim to do is to make the student aware of pitfalls that often are the source of unnecessarily painful experiences, damaging self-doubt, and needless prolongation of the time for completion of the graduate program.

To a large extent, the endeavor of graduate study can be characterized as one of learning on the job. In a way it resembles the medieval method wherein an apprentice learned a trade by working with a master. Most graduate students are educated in much the same way; by working with an academic advisor, they learn the trade of science while doing research. The process of learning is largely based on imitating the adviser and other faculty members, and being corrected when things don't go smoothly.

This on-the-job-training method of education works well enough in that most graduate students will have learned to carry out science independently by the time they receive their degree. This, however, does not mean that it offers the optimal way to prepare graduate students for a career in science. This mode of learning has two disadvantages. First, learning on the job implies that making mistakes often plays an unnecessarily large role in the learning process. Mistakes, to be sure, can be a powerful and valuable teacher. Those that could have been readily foreseen and avoided but were not, however, cause delays and are potentially harmful stumbling blocks. Second, many of the lessons for junior researchers can be conveyed more effectively by exposing them explicitly, as in this book, rather than implicitly, as when all learning is on the job.

Consider the following example. Writing is difficult for most people. It certainly can be so for a beginning graduate student who starts to write her first major paper. Often the student agonizes and writes the first draft with great difficulty. She next gives this draft to her adviser. More often than not it can be expected that the adviser will disagree with aspects of the basic structure of the manuscript, the conclusions that are drawn, or the style in which the results are presented. The resulting necessity of having to do a major rewrite of the manuscript then contributes to mounting frustration and often loss of confidence of the student. As shown in Section 10.3, this problem largely can be avoided by developing effective writing habits and by being mentally and emotionally prepared to understand that iterations of the drafts between adviser and student constitute an expected and potentially productive process. A good deal of important scientific advance takes place during the draft-iteration process.

As in learning any new field or occupation, mistakes along the way during graduate study are inevitable. With the benefit of lessons learned from the experiences of others, however, many *unnecessary* mistakes and pitfalls, while engaged in a research project, can be avoided, thereby helping to shorten the time spent in graduate study and make that study a more positive experience. Since most graduate-student projects are carried out under both time-pressure and a tight financial budget for the student, avoidable delays are undesirably costly. Of more concern, the related frustrations for the student lead to the second disadvantage of this mode of learning – a most unfortunate one: the drop-out rate of students from graduate school is higher than it needs to be.

Graduate students can be better prepared for a career in science if they have an explicit understanding of the many issues that arise as they are about to embark on that career. To help prepare students for a career in science, one of us started the course "The Art of Science" at the Colorado School of Mines. The course is aimed not at providing a philosophical treatment of the process and nature of science. Instead, it aims to help prepare graduate students for a career

in science by teaching them practical skills and offering insights that can be beneficial in carrying out science, with a primary goal that their graduate-education experience be both enjoyable and efficient. Many of our colleagues at different institutions agree with our perception that there is a real need in most graduate programs for education along the lines of this course. It provides beginning graduate students with general skills to carry out research more effectively at an early stage of their career. The following quotes taken from evaluations of the course are fully representative of benefits that students perceive:

> *"We are getting counseling that students typically don't receive from an adviser. I for one appreciate it."*
>
> *"I enjoyed your approach to research planning, problem solving, and personal development. I will certainly recommend your class to other students!"*
>
> *"I have learned that there are many people encountering the same kinds of problems that I have in my research."*
>
> *"The course was very useful, although I think it would have been even more useful if I had taken it when I just started my Ph.D. research."*
>
> *"This class should be a must for any graduate student."*

These statements provide support that a course that covers material such as that in this book can be highly useful for graduate students. Students consistently indicate that they feel such a course would be most effective if taken early in the graduate-school career. It is a relief for students to discover that many fellow students struggle with similar issues, and that they can often help and support each other in resolving those issues.

Offering this course as a 1-credit course for one semester has been the best compromise between the depth and breadth of material covered, and the needed time-investment by students. Appendix B shows a possible curriculum for such a course that serves to give instructors ideas about topics and activities that one could use.

Material in this book can also be selected for use in a short course with a duration anywhere from a few hours to several days.

For whom is this book written? This book is written primarily for students who pursue a Master's or Ph.D.-degree in science, engineering, or the humanities. Since we describe the development of effective research habits, the material is also of relevance for undergraduate students who are planning a career in research, or who simply want to know what it takes to be an effective researcher and what a career in research might involve. Although the advice in this book is primarily aimed at students, this material can also be of relevance for advisers of students as it could help them to be more effective in their role as mentor. Last, this book provides ideas about the practice of research that could be of value to freshly degreed researchers, as well as to those already well into a research career.

An overview. Numerous excellent textbooks on the philosophy of science have been written. Rather than giving an overview of this fascinating topic, we present in Chapter 2 a description of essential elements of the scientific method. We make the case that, even though science is based on logic, progress in science is driven by insight, intuition, and inspiration. We also argue that the scientific community is diverse in its methods and approaches, and that this diversity is essential for making such progress.

Making the right choice of research group, adviser, and project is of crucial importance, yet students often flounder when starting a research project that is not the right fit for their interests and background, or when working with an adviser who does not meet their needs or expectations. Graduate students need to understand the considerations that should go into the choices of a research group, adviser, or research project. Guidance for making this choice, and other underlying ones, such as the choice of university, department, and adviser, is given in Chapter 3.

Because the choice of adviser can have such large bearing on the extent to which you do or don't *thrive* in your graduate study, in Chapter 4 we discuss the many different styles of advising and how

these styles might or might not match with your personality and strengths (and weaknesses) as a novice in research.

We often think of research mainly as a process of solving problems. Most frequently, however, the largest scientific breakthroughs come primarily from asking the right questions, which comes about only after freely posing *lots* of questions, many of which will be off the mark. The role of asking questions is emphasized in Chapter 5. Once having posed questions that help frame your planned research, you measurably sharpen focus on the research path you will be following by organizing your effort into a formal (but alterable) workplan, as discussed in Section 5.3. The workplan is of critical importance when you are working alone, but even more so when your research is to be conducted within a group.

Chapter 6 offers advice on a number of systematic steps you can take to aid in the efficiency with which you carry out the workplan. Part and parcel of that workplan and how you go about carrying it out is the direction that you give to your work, founded on goals that you explicitly set, steps that you take in working toward those goals, and resources that you call on toward these ends. That chapter also reveals issues that bear consideration as you form your goals.

As in all aspects of life, the pursuit of scientific research is fraught with potential pitfalls. Also, as in life, when an apparent pitfall is recognized, the need to address it can offer an opportunity for a wonderful breakthrough. As amplified in Chapter 7, the key is in first recognizing the existence of the paradox or other sticking point and then realizing that it can be caused by a misunderstanding that you have had about the problem. The chapter continues with advice on making the most of confusions that inevitably arise during the course of research.

We might think that the purview of ethics and ethics violations is restricted to the professions of law, medicine, engineering, business, and politics. Not so. Each profession has its own specific codes of right and wrong behavior, in addition to those common to all fields of endeavor. Nothing can be more thoroughly damaging to a career in

science than the loss of respect for the scientist's integrity and sense of fair-mindedness. The critically important topic of ethical standards in science and adherence to those standards is covered in Chapter 8.

Whatever the purpose of your research, it is essential that you dedicatedly follow the literature, not only at the outset, but throughout the course of all stages in your research. In Chapter 9 you will find efficient ways to use libraries and other modern sources of information.

The pursuit of science entails much more than defining a research problem, posing the right questions, and thereafter successfully solving the problem. Satisfying as having reached a solution might be, the scientific endeavor is incomplete until the outcome of the research is communicated broadly and well to the pertinent scientific community, and sometimes beyond to the lay public. Communication with clarity and in a manner that draws and maintains the interest and attention of the intended audience is an art whose development, for most people, requires dedicated care and attention. The task in communicating research results can often take as much time and effort as the research itself, as is emphasized in Chapter 10.

Knowing how to choose a journal that is most appropriate for your paper entails a number of considerations, and having an awareness of the submission and review processes (which vary from one journal to another) can help in minimizing consternation. Chapter 11 gives advice on these issues as well as tips for distributing your research results to the relevant group of readers.

Readily one can follow all of the guidance in the chapters reviewed above and yet fall into any of many lurking traps that divert time and attention needed to complete the research as efficiently as possible. Time management is yet another art form whose mastery eludes many people. Chapter 12 warns of time traps and offers ways of circumventing them.

Unless you are an independently wealthy renaissance scientist, you will need to secure funding for your research, if not while a graduate student then certainly in your subsequent career. Therefore,

unless you have a sympathetic benefactor, the writing of proposals is in your future. Chapter 13 treats many facets involved in writing proposals, such as targeting an appropriate funding agency, knowing how to locate opportunities for funded research, knowing what are the elements in an effective proposal, and knowing what to expect in the proposal-review process.

A research project, whether conducted while in graduate school or in your career thereafter, ought not be considered an isolated entity. Rather, it can often purposefully be part of a larger goal or set of goals that define your research career. You can expect that your scientific career will follow a serendipitous trajectory that is recognizable only after the fact. You nevertheless can provide for a more satisfying and productive career by defining and working toward goals that you explicitly believe to be especially right for you, including those that are consistent with larger *meaning* that you wish to give to your life. Chapter 14 gives tips that can be useful toward that end, but expect that the best laid plans . . .

What will your career be? Depending on your personality, interests, and perhaps sense of mission, it could be one in industry or academia. Also in Chapter 14, we contrast careers, exposing both differences and similarities one might expect to have in industry, academia, and national laboratories. Moreover, frequently these days individuals choose to, or at least expect to, change their employer, their type of work, or function within the organization, and even their core career direction, for example, to a totally different scientific area (such as from biophysics to computer science) or from science and technology into management. Chapter 14 alerts you to such wide-ranging career issues.

Once you've successfully defended your thesis, you've almost launched your career in science. The next step, a key one, is successfully obtaining the job that you desire at the institution (university, national research laboratory, or private corporation) of your choice. Covered in Chapter 15 are a number of elements that enter into successfully obtaining that desired job. These include establishing

contacts within the organization, the writing of a *curriculum vitae* (CV), how you approach the interview process, and factors to consider in assessing the organization and its practices.

Numerous books serve purposes that parallel those in this book. Some are listed in Appendix A. A sample curriculum for a course based on the material of this book is shown in Appendix B. Appendix C gives an overview of two common database formats for bibliographic references that are particularly convenient when writing multiple papers with overlap in their lists of references.

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