Didn't we tell you the rules have changed?

A primer on how to be a graduate student
in physical science or engineering

by

Dr. Charles A. Doswell III

Preface

As with my first book, for undergraduate students, this book is an outgrowth of several years of experience in talking with students. It is based in large measure on my own experiences as a student. I had to learn how to become a successful student without much guidance, but for reasons that I still don't understand, I made a large number of basically correct decisions about the process. I became a successful student and that success has led to what I consider to be a very satisfying and rewarding career in meteorology. As I have looked back, my decisions as a student were crucial in that career.

Graduate school is a special place, and a successful graduate experience can be among the most exciting times of your life. But making graduate school a good experience requires something much different from what you have been doing up until now. When I began to advise graduate students, I found that many of their difficulties arose from what are basically correctable misconceptions about what graduate school is all about. I have regaled most of my students with the contents of this book over the years and I believe (hope) that it has helped a number of them. Perhaps it will help you.

Since you've identified physical science or engineering as your career goal, you should understand what graduate school is and is not going to do for you. I suppose it seems as if you've been going to school for a long time and you deserve to know what you're getting for your commitment to several more years of study. In some sense, that's what this book is about, but I can say at the outset that you should *not* expect to learn all that you will need to know for your chosen career from your graduate studies. Graduate school is, in the best sense, a place where you finally reach the point of learning *how* to learn. This will be enough to carry you through your professional career, so it's a useful goal. It should be your primary goal going into the experience.

I. Introduction

So you've decided to see if graduate school is for you. In the physical sciences, graduate school is the key to many doors that will remain closed to you without a graduate education. Although engineers and some scientists can pursue many of their career options with a Bachelor's degree, there are many *more* options for those scientists and engineers who choose to go on. At this point, apparently, this is a choice that you have decided is in your best interests. Or you are thinking about the situation, at least. Or you couldn't find anything better to do after you finished your Batchelor's degree.

In any case, I should not have to spend much time talking about study habits and so on. It is likely that you have negotiated your way through most of the early pitfalls that await undergraduates: time management, distractions, and drugs of various sorts (including alcohol). Nevertheless, I am going to have some things to say, here in the Introduction, about keeping yourself together. I am still teaching and I still find incoming graduate students who *don't* have a clear picture of *why* they're in graduate school

Some of you have come from programs where you weren't challenged very much. You may have thought you were working hard and making progress (and good grades measure that, right?). Well, for some of you, graduate school in the physical sciences or engineering is going to be a rude awakening. If you were valedictorian in high school and made a 4.0 (or close to that) as an undergrad, it may seem like you are on a roll and have every right to expect to breeze through grad school in the same way. Success has been a hallmark of your academics, in general, with very few slip-ups and mostly high praise for your work. What worked in high school seemed to work in college and as far as you know, this is going to be more of the same. As I shall try to discuss, the whole game has changed here in graduate school and the techniques that worked for you during the last eight years almost certainly will not cut it anymore.

Others among you may have struggled through high school and your first four years of college. Perhaps you've been bored with the offerings and have not extended yourselves for lack of enthusiasm. You may be in graduate school with little or no real understanding of what is about to happen to you; it was easier than going out and landing a real job, so why not give it a whirl? It may be that you've wanted to get focused on some aspect of science or engineering, while the curriculum has been forcing you to fill your schedule with stuff you don't like very much. In my own case, I'm afraid I was in this group of marginal achievers; sort of limping along with slightly better than average grades, but nothing to get very much attention. I was constantly being told that I had not lived up to my potential, to the point where I was

really not listening to that sermon anymore. My grades peaked when the subject interested me and dropped when I got bored, or I didn't like the teacher's methods. I had a goal to be a meteorologist, but I hadn't had anywhere near enough of the subject. If you're in this situation, you may well find graduate school is your chance to really get into the subject at which you are aiming yourself, and this might bring you to the realization of the potential with which everyone has been saying you aren't doing anything.

You need to understand right away that graduate school is an important watershed in your life. Some former high achievers will burn out and drop away. Some formerly mediocre students will leap to the top of their peer groups. You're now most definitely a young adult, not an old teenager. Dormitory living is probably behind you, although you still may need to share expenses with a roommate. Some of you will be married; if you are married and your spouse is not a student, be prepared for some stress on your marriage; I'll have more on this later. Running your own personal life is something you've become accustomed to, and you should not be intoxicated with freedom anymore. Chances are you already have some good study habits, which are going to be tested, but you will soon find that classroom learning is only a tiny part of what you need to do.

II. Issues

A. Didn't we tell your the rules had changed?

This book's title is meant to let you know that this experience is going to be quite *different* from anything you have experienced to date. Going from high school to college was mostly a change in your personal life. For the most part, the academic side of things in college was not that much different from what you had already experienced. The big challenge was to manage the out-of-class part of your life. Classwork was pretty similar to high school. If you are about to enter graduate school, it appears that you have become reasonably good at classwork, by now. Now the time for a major change in your academic life is about to take place.

Undergraduate classroom lectures have mostly been "dispensed wisdom" with the professor (or TA) pouring out knowledge as you try furiously to keep up with the presentation, take notes, and understand what is being dispensed. Generally, the professor is regarded as an oracle, the source of knowledge, the adjudicator of the correctness of your answers on tests. Tests have been dominated by questions for which there is one right answer (the one given by the professor, who may even have written

the textbook you've used). Grades are dominated by objective (multiple-choice) test scores and homework exercises have been aimed at teaching you how to use the class methods to come up with the right answer.

Every once in awhile, you may have run into a professor or TA who approached things a bit differently, with more open-ended questions and answers. The ones who have given out word problems and essay questions have been relatively rare, and you may well have griped about those. Teachers who asked questions of you in class have been unusual, and if class time was spent in arguments among students, that time was minimal. After all, we must keep up with the syllabus (or "silly bus" as I like to call it). The professors and TAs ran the class, and you were expected to sit in your assigned seat (or stay in the one you selected). Basically, it's been a lot like high school.

Well, the rules have changed! Didn't anyone tell you? No? Graduate school is gong to be *different*. You are going to have to learn how to think for yourself. Lecturers are going to become increasingly Socratic, answering your questions with more *questions*, not dispensed wisdom. To an ever-increasing extent, there are not going to be pat answers to the questions you're going to be asked, or that you are asking. Non-objective scoring is going to creep into your life. Word problems and essay questions are going to show up more frequently in your tests and homework assignments. You may be getting *take-home* test and, heaven forbid, even some *oral* exams! Class projects are going to get more and more challenging, taking on a very *researchy* flavor. Class sizes will shrink down to as few as five or six students with a professor, and only occasional TAs.

Instead of sandwiching career-related classes in your professional line between Contemporary Spanish Literature and Political Science, your schedule will include a lighter course load but it will be packed with mathematics, physics, engineering, and science classes. You'll progress quickly into advanced material. Whether you knew it or not, most of the material you studied as an undergraduate was developed before the 19th Century! As you move toward the back of the catalog into the upper division graduate courses, the development date of the material will race forward in time, and you'll begin to encounter 20th Century ideas. Perhaps toward the end of your graduate careers, you might run into really recent scientific and engineering ideas, possibly even those still being developed. It can be heady stuff, and certain among you will flourish with this challenge, while others will wilt under the pressure. And there *will* be pressure. More than you've ever known. If you think you were challenged before, you might discover that what you thought was a challenge before was really a cakewalk.

Make no bones about it. Graduate school is *not* intended to be a cakewalk. Challenges of increasing magnitude will be thrown at you and, if you conquer them easily, the next round will be a *lot* rougher than the last. How you respond will determine how successful you will be for the rest of your career. You're going to be forced to reduce your non-academic life to a mere shadow of its former self. Grad school is the time to focus; it's a period when you really need to develop tunnel vision and restrict the time spent away from your studies to the bare minimum necessary to stay sane. Don't worry; you're *not* going to turn into a one-dimensional person ("nerd" or "dweeb" or whatever) by doing this! Living like a monk for a few years is *not* going to ruin your social functioning ability. To become *really* good at something, everyone needs a time in their life where they put their heart and soul into it for a time. What *better* time to accomplish this than during graduate school? Most of you still have minimal family responsibilities, you're accustomed to a student's life of relative poverty and lack of respect (more on this later), and you're working to achieve something you've dreamed of having for years. Why *not* put out this effort during graduate school? If not now, *when*?

B. Grades

You probably have heard already, but the grade system has changed in most graduate schools. In grad school, getting a "C" means you *failed*! If you manage to get a "D" or "F" you can plan on packing your bags, more or less right away. One "C" in most graduate schools will get you on a probationary status, and there had *best* not be another! Of course, professors know what this means, and they are reluctant to hand out a failing grade, so your graduate school transcript should be all "A" and "B" grades. If it's not, you won't finish, because you'll be asked to leave. You probably think that a 4.0 average (or whatever all "A's" translates to) is something you want. Well, that isn't necessarily so. Most of the reason why it might not be so depends on *how* you got that 4.0 average. I'll be discussing what a "full load" means in graduate school, because it isn't the same 15 semester hours or so it was when you were an undergrad, but for now I'll say that if you take *less* than a full load because you want to get all "A's" on your transcript every semester, that is not going to look very good. If you took a full load, but padded it with simple courses that you could "ace" easily, then that will show up, as well.

I discussed this topic at some length in my book about undergraduate school, so I'm not going to dwell on it, here. Suffice it to say that in graduate school, more than ever, if you concentrate on learning

everything you're taught, and *more*, then the grade situation tends to take care of itself. The courses you take should be challenging you, with new material coming at you pretty fast. If not, you're loafing! Find classes that you are *not* sure you can get the "A" in! Take risks! Now is your last chance to learn with someone guiding the process, so take advantage of the opportunity to challenge yourself in a situation where a few stumbles don't mean total failure. If you do this properly, you may well end up with a few "B's" to go with your "A's" on the transcript. Should this be the result, then you probably succeeded in challenging yourself properly and the less-than-perfect grades do *not* make your transcript look less attractive than a 4.0 transcript produced by someone who took no risks. A 4.0 transcript looks suspect to many of those prospective employers.

C. Graduate school and your career

Presumably, you've made the choice to attend graduate school because the career choice you've made for yourself virtually requires it. If you don't know this with a crystalline certainty, then you need to find out right away, preferably before you even start. Going to graduate school to avoid going to work is not a good plan (I'll have more on this later), and going to graduate school because it someone told you it was the right thing to do is not good enough. You need to *know*! Why? Challenging yourself is the key to graduate school success, and if you don't know why you're doing this, you will tend to make the *easy* choices rather than the *right* choices. If you don't really need grad school to do what you want, of course, it shouldn't hurt to go through it, but it's possible that someone might consider you "overqualified" to do what you want to do. Personally, I've never understood what "overqualified" means, but apparently it does happen. The perspective I prefer to take is that if you don't need it, why waste time with it? Go on and start doing what you want to do with your career *now*. You can always come back to school if you discover that your assessment of the situation was wrong (more on this later, also).

In my field (Meteorology), there are many jobs for which a Bachelor's degree is all the academic qualifications you'll need (right or wrong, this decision has been made by some employers). You can choose to enter such jobs soon at a relatively low level and work your way up the career ladder. Getting graduate degrees does tend to increase the entry-level salary and expectations about your capabilities, however. Graduate school starts you out higher on the ladder but you have delayed entry into the system by going to graduate school, such that someone starting two or three years earlier than you might well be

at your entry level already through relatively rapid promotions.

In some sense, the choice is yours, and you have to decide what seems like the best way for you to go about developing your career. Part of that decision is finding out what is appropriate *in your field*. Ask questions of the faculty, and if you can find folks outside the university, ask them, too. It is important to talk to people who are actually doing what you intend to do. The academic process associated with obtaining a graduate degree may be helpful in obtaining some job situations that are closed (or at least difficult to gain access) for Bachelor's degree employees, no matter what their experience and job performance may have been. It's in your interest to know what that job market really holds for you and getting input about this is up to you. I can offer suggestions, but the path you want to follow will dictate to whom you need to direct your questions.

D. The choice of a terminal degree

In the same way that graduate school itself is a choice you have to make, if you have decided on graduate school, the next question is what your *terminal* degree requirements are. For many science and engineering jobs, a Master's degree suffices. In most cases, non-research-related jobs will not even require a Master's degree but they might consider a Master's degree an important supplemental qualification. Research-related jobs almost always are associated with a graduate degree. If the expectation is that the employee will be doing *independent* research, with little or no scientific or engineering supervision, then a Doctorate is virtually necessary. Faculty positions at virtually all universities, especially those associated with research, require a Ph.D. (or equivalent). Having less than a Ph.D. in an employment situation with a research institution of one sort or another is tantamount to being a support scientist (or engineer), doing work under the direction of a Ph.D.-level supervisor. Naturally, if this sounds satisfactory to you, there is no shame or loss of true stature in doing support scientist work. My point is that you have to decide what you really want to do in order to make that choice.

It's also important to understand as you enter graduate school that you should not impose *artificial* limits on your horizons. If you would love to do independent research but are not sure you have the capabilities, go ahead and try to achieve what you want! If you don't at least try, then you will never know what you *could* have achieved. How do you know what your limits are if you've not found out what they are? Furthermore, you don't want to get 20 years into your profession and realize that you made a mistake

by stopping your academic program too soon. It's *not* too early to think ahead about how you are going to l*ook back* on your career. As you go on in your career, you will encounter many people who sold themselves short and achieved much less than their desires because of this sort of uncertainty about their abilities. Now they are embittered or very unhappy because their options have all closed down; for one reason or another (often related to family responsibilities) they're locked into a career that will not allow them to achieve what they really wanted. Is that what you want? I don't think it is, so my *general* advice is to go as far as you can, as soon as you can.

If you are not convinced you can do it, but you *need* to do it in order to have your heart's desire, then by all means, keep going. If you fail, then the effort will still not be wasted if you learned *anything* at all, and you *will* know your limitations, which is not a bad thing. Everyone has limits, but many people are afraid to test them. By not taking risks, they *guarantee* that they will achieve less than what they might have. Would you rather be someone with a lot of ability that only uses a part of it, or someone who achieves many things within their range of ability? I like the aphorism "It's not a matter of what you have, it's a matter of what you *do* with what you have!" My experience is that many who have much do little, and those with less often do more than those who have much. It is rare for really gifted people to achieve a lot in science and engineering, because it comes too easily for them. If you have to work hard to achieve your dream, then I think it more likely that you will indeed achieve it than someone for whom the path is easy. Graduate school is littered with talented dropouts. If it comes hard to you, then take heart! You may be one of those who can live their dream. Keep going after a stumble or a setback and it's not really a failure at all.

E. Teaching and research assistantships

After that little pep talk, let's get back to business. Having an assistantship is a way to obtain financial independence; for some (perhaps most) of you, this will be your first taste of real financial independence. Assistantships in general have been figured to be marginally capable of supporting a frugal graduate student, so you're not going to get rich while you go to school. In fact, it's likely to be a real challenge to survive on just an assistantship, because there are no allowances for luxuries, like your own car or an extensive social life. Be prepared to pinch your pennies, if the assistantship is your sole source of income.

Because your assistantship means you can support yourself, the notion of a full course load changes. It becomes quite a substantial load to carry three courses (the equivalent of about 9-10 semester hours) per term, instead of the five or six you took per term as an undergrad. Of course, if you're independently wealthy, then I suppose you could take five or six courses, but I suspect it would be really difficult, because each graduate level course is designed to be *challenging*, if you recall. If your assistantship is a typical "half-time" assistantship (they expect you to work around 20 h per week on your assigned task), then three courses is usually quite enough.

In the typical value system associated with assistantships, the professors like to grab the most promising students for their research assistantships (RAs) simply because they want the best students they can get. RAs are usually supported by grant money, where the professor has had a research proposal funded and RAs are assigned the hard labor of getting the research done; they become support scientists. Since professors get funded on the basis of the expectation that they will do important and useful research, then they want the best student help they can find. Good research means important publications, which is their ticket to getting more of their research funded.

This not-altogether-cynical system may have one unintended by-product, unfortunately. The teaching assistantships (TAs; remember them from your undergraduate days?) often thereby go to the *second* tier of grad students. In many departments, there is an unspoken negative association with being offered a TA instead of an RA. If your memories of your undergraduate days are tinged with negative feelings about the TAs you encountered, this is a partial explanation for those feelings. On the other hand, some departments feel that their best and brightest students *should* do some teaching as part of their academic growth. Moreover, professors are not infallible in skimming off the cream of the graduate students for their RAs. Good students get missed, in part because the undergraduate performance is not necessarily an accurate measure of graduate success. And there may even be good students who really *want* to teach, because their vision of their career involves being a good teacher. It is such students who provide a real service to their universities and are grossly underpaid and underappreciated for that service. It's just a part of the deal, and what satisfaction goes with doing a job well may be your primary reward for a stint as a TA, apart from the minimal pay you receive.

If you have an RA, the work that you do for your professor often is the work that you will write up for your thesis or dissertation. Such situations are probably the norm, but it is by no means guaranteed.

You may well end up turning the research crank for your professor and then have to work out your thesis research on your own. This is not the easiest thing to do, but then I have stressed that the *easy* path is not always the best path for your career development. If this should happen to you, the only consolation I have to offer is that it probably can be viewed as an *opportunity* for you to grow; in the long run, such a challenge could serve you very well. Students that have had the easy path, where their RA work was also their thesis work, will almost certainly not be as strong as you will become if you can pull it off.

III. On the curriculum

A. Mentors and advisors

A really important issue arises as soon as you enter graduate school. Who is going to be your academic mentor (or advisor)? If you are being supported on an RA, that person is generally going to be the professor who pays your RA. The mentor's role is far more than just someone who approves your curriculum choices, as it was during your undergraduate days. There are many views of the mentor's part in your academic development, but I will offer mine.

Because the notion of mentorship has come into vogue recently, there is abundant material on the subject, if you are willing to look for it. To me, the mentor is something like the master craftsman who takes on an apprentice. By choosing a mentor, whether you realize it or not, you have chosen a person after whom you want to model your career. You will learn the "craft" according to the mentor's view of it, so it behooves you to choose carefully, right? Unfortunately, as you enter the profession in graduate school, there is precious little information available to you about *whom* to choose as a mentor.

By accepting the offer of a professor to support you on an RA, you have, de facto, chosen your first mentor. This may or may not be a wise choice, and you may not even realize you made a mistake until after you've left school! There are some things to consider as you make your decision.

1. How many students has the mentor taken through to graduation? If a high percentage of that person's students do not complete the program, then this person may be a poor choice. Of course, it may be that he or she offers students such a challenging program that many of them have chosen easier paths. Talking to some of the students might give a clear picture of what the reasons for a low graduation rate under a particular professor; beware that you do not limit your

sample to only disgruntled mediocre students.

2. If there have been several graduates under this mentor, what has happened to them? Have they gone on to be successful scientists or engineers, well-recognized for their contributions? Or have they disappeared into obscure jobs with little or no impact on the profession?

3. How well do *you* interact with this individual? Even the best educators find that there are students with whom they simply don't "resonate" and the students can flourish under someone else. Note that you do not have to *like* your mentor and the mentor does not have to like you for the relationship to be successful in achieving your career goals. Mutual respect is necessary, but respect and affection are not synonymous.

4. New faculty are generally unknown quantities. It is hard to tell how good at mentoring brand-new professor will be. Look at what they did and how they did it during *their* graduate student days and in the time since graduation. If they have done things a certain way, chances are good that they will expect more or less the same things from you.

5. Fame within the profession is *not* a good measure of how good a mentor that person will be. Often, famous faculty are very busy and may not have the time to nurture you in your development. Faculty members with big egos as a result of their fame typically do not work well with talented students, who can be perceived as a threat to the ego of the mentor. Of course, not every famous person has a big ego or is too busy to worry about your needs, but these are common problems. If a potential mentor has written a textbook, it often is possible to see what their teaching style is by reading their textbook, but you should use this with caution: a mentor's classroom interaction style could be quite different from their *writing* style.

6. Beware of the advisor who gives you too much *freedom* in your Master's thesis work. A Master's thesis should be guided research, where you are just learning what research is all about. Conversely, beware of the advisor who gives too much *advice* in your Doctoral dissertation

research. The Doctoral dissertation should be your work, not an extension of your mentor's wishes. I'll have more on this later.

It may happen that an advisor is selected *for* you. This may be department policy or simply because you have no clue about whom to select. Such a situation typically is regarded as tentative and you can change advisors after you have had a chance to look around, ask questions, and do some investigating on your own. Clearly, I recommend you do all of that, even if you have selected someone and it is imperative if someone was selected for you. This is too important an issue to be left to chance. If you end up working for the wrong mentor, you can have real problems later.

If you consider the advice I have given you just now in point #6, there is an interesting possible implication. Suppose you already know roughly what general topic area interests you the most. Generally speaking, it is commonly-accepted wisdom to select an advisor who is considered well-known in that topic area. This is especially true for the typical Ph.D. situation. However, I want you to consider that your best bet for a Ph.D. advisor is not necessarily someone doing work in the specific subfield you want. I'll have more to say on this below. For the Master's degree, the most important issue is that your advisor is doing meaningful research, or has a good track record of being able to teach students how to do research. I'll discuss this again.

Your advisor need not be your *only* mentor. Most of you will be heavily influenced by faculty members other than your advisor, and they all can be considered mentors. If you find a teaching faculty member whose courses you find interesting and challenging, take every course you can from that professor or TA. That person can have a powerful influence on your career even if he or she is not your advisor. Put such persons on your Advisory Committee ... which brings us neatly to the subject of the Advisory Committee.

B. The Advisory Committee

Most graduate schools require the formation of an Advisory Committee in one form or another. The Chair of the Advisory Committee is typically your formal Advisor, and the other members of the committee can come from your department, other departments in allied fields, and adjunct faculty (perhaps from other universities or from institutions other than the university, like research laboratories). There are

at least two quite distinct attitudes your Advisor (sometimes known as your *Major Professor*) can have regarding your committee:

1) the committee is a resource that broadens the range of opinions and expertise available to the student (and the Advisor) during the process of pursuing the research and developing an appropriate academic course of action, or

2) the committee is a group of meddlers whose only value is to satisfy the formal requirements for a committee and are best left out of the whole process until the very end.

Obviously, I view the latter as the perspective of a poor Advisor, and recommend getting out from under the clutches of such a person as fast as possible.

A committee can serve many useful purposes. If you put someone on your committee, it must be with the approval of your Advisor, so there should be mutual respect among the committee members. Diversity is nice, but you're asking for lots of trouble if your committee includes members who are in bitter conflict with each other. It is not uncommon for committee members to disagree over some scientific (or engineering) point, but they should not make *you* a focal point for their disagreement. It is useful for you to understand that different opinions are a sign of *health* in the profession, not a problem that *you* need to resolve. Neither science nor engineering are the black-and-white professions many non-technical people believe them to be. The trick is to have just the right sort of diversity on your Advisory Committee: some diversity is good, but open warfare among the members is almost certain to spill over onto you.

Having occasional consultations with all your committee members outside of formal committee meetings is a good way to avoid unpleasant surprises as your degree program nears its end. If they have problems with what you are doing for your thesis work, it's good to know that early and have time either to modify what you are doing or to find a way to convince them it's O.K. Committee members also can offer valuable opinions about what courses to take, as well as other useful recommendations (such as career options) along your path. If your department requires an Advisory Committee for graduate work, then it is simply stupid not to take advantage of the opportunity it represents. These are people who have made *a*

formal agreement to help you. Use them!

C. Selection of optional courses

During graduate work, formal coursework assumes a diminishing role in the process. Whereas courses have been essentially the entire program through your undergraduate school, the rules have changed in graduate school. You have become accustomed to repeating "dispensed wisdom" during school up until now. Thinking for yourself is an occasional, often uncomfortable exercise only a few teachers have asked of you. In graduate school for science and engineering, you are embarking on a course designed to leave you capable of creative thinking on your own, at the very frontiers of your profession. Coursework is only a part of what you need to get there and, if you complete a Doctoral program, you will finish your program in school but you won't be taking courses at the end! Done properly, courses will get you to the point where you can teach yourself whatever new things you decide you need, without the crutch of someone there to guide you through it. In terms of mastering new concepts and techniques, the goal is to achieve a "critical mass" such that you no longer need teachers.

Hence, your considerable new freedom to design your curriculum in graduate school is an important responsibility. You are given that freedom because 1) not everyone needs the same things when they arrive at graduate school, and 2) there is more specialization in graduate school than in undergraduate school. Not all the entrants in a particular department's program have in fact come through that particular department. Incoming graduate students may not even have majored in that course of study during their undergraduate days. It is not at all uncommon to change majors after undergraduate school, so some students may have coursework content deficiencies to make up. Other students who have majored in the subject during their undergraduate days may want to broaden their expertise in allied fields, notably in mathematics and computers for science and engineering majors.

Graduate programs at different institutions have different strategies for dealing with this variety of incoming graduate students. They may have a relatively small set of *core* graduate level courses they require everyone to take (and *pass* at some level) to obtain a degree in that field. Alternatively, they may give a comprehensive examination late in the degree program that they consider to cover the core material, and require some minimal score for passing. Some schools may do *both* of these. In any case, there will some set of requirements that still allows the student a chance to pick and choose among many options.

1. *During a Master's program*

If you have read my advice to undergraduates, you will remember that I suggested it is wise to avoid being too specialized in your Bachelor's degree curriculum. At the incoming graduate level, this changes. Now, during the Master's degree, is the time to dig *deeply* into the subject (a typical requirement for a Master's degree is about 30-35 semester hours, or roughly 10 courses). If you want to know something well enough to be creative at its very frontiers, a superficial understanding is not going to get the job done. This does not mean that you take only courses from within your department, however. Depending on your background, you may well want to diversify by taking challenging courses in related fields, especially if you majored in the subject as an undergraduate. There also will be important core courses within your department you need, as well as key specialized courses that will probably be taught there as a result of having particular individuals on the staff who have specialized in those areas. Presumably, you *chose* that graduate school over others because those faculty members were there and teaching that particular material. This is the moment you have been waiting for; you have suffered some during your undergraduate days taking required courses you really wouldn't have chosen. Well, for the most part, your course load during your Master's degree will tend to be really focused on your chosen field (and closely-allied fields).

These can and should be heady times! You finally are digging into the things about which you've always wanted to know. This should not be "work" in the sense that doing something you don't want to do is work. You should be enjoying this labor; doing classwork now should be *fun*, not work! If it *seems* like work to you, then I really want to recommend you think this thing through, thoroughly. Having to force yourself to do the things you've waited years to do is a major distress sign that this field may not be what you want, after all. Moreover, in any particular course, you can no longer afford the luxury of whining about the quality of the teaching. You may well not have an unbroken string of great teachers, but *this* is the material you signed up to learn. If you get a bad break and inherit a poor teacher in some course, you still need to master the course material: to know it backwards and forwards and inside out, whether you like the professor or not!

Enrollment in your classes is going to be smaller than ever, with as few as five or six in the smallest classes. There aren't many really incompetent students left, although the majority of students are

still mediocre. The small classes increase the informality of the course, and you should be more familiar with the professors and TAs (fewer TAs than ever, of course). There will be less "dispensed wisdom" content than ever, although not every class will be the same in this respect.

With any luck at all, you're going to encounter more and more challenges as you go. The course load in terms of semester hours (or whatever) may be lower than in your undergraduate days, but the stuff should be coming at you fast and hard. You should be *stretching* to learn it in the time available, learning new things at an accelerating pace along a path of ever-increasing complexity. Success means more confidence to do even more next semester. Occasional setbacks are simply bumps along the path, to be overcome quickly so as not to delay the process any more than necessary. You will make mistakes, no doubt, but you should *learn* from them, as they are even more valuable to you then than your successes! New ideas should be swirling around madly in your head. Questions and more questions should occur to you. The fraction of *dumb* questions you ask should be diminishing, almost without your noticing it. (If you read my book about undergraduate school, I asserted that there *are* indeed dumb questions, but you'd better get them answered, anyway!)

2. During a Doctoral program

If you've made it this far, you better know that the rules are changing once again. The coursework requirements at this point are usually pretty vague, and you almost certainly have more freedom than ever before (or again) to pick and choose. This freedom reflects the most important rules change you are going to experience. If you complete this program successfully, you're about to enter a career where many people will be looking to you for leadership. It is imperative that you begin the process of cutting the umbilical to your mentor(s). There may well be a few courses left in your department that, for some reason or another, you have wanted to take and just haven't gotten to them. The doctoral level coursework need not be at the very highest level, if there remain some gaps you need to fill, especially in allied fields (or in the departmental offerings, if you came into the program as a prior non-major).

However, you should be approaching the "critical mass" I spoke of earlier. Rather than a heady succession of increasing challenges, course work should be more like mop-up work to you as you finish up your Doctoral program requirements. With any luck at all, the timing of the loss of challenge in coursework will coincide roughly (within a semester or so) with the completion of your coursework

requirements (about 30 semester hours, or about 10 courses, again).

The average class size probably will continue to decrease some over those in your Master's program, but not too much. You might take courses where you are the only student; special courses dealing directly with the professor. Learning analytical methods is less important than being able to learn them as needed on your own, so you should be sure that you have enough coursework behind you to do that. The courses that will be of greatest value to you will be those that emphasize class projects, independent reading of scientific (or engineering) literature, critical thinking (i.e., critiquing technical material), discussion groups, and such. The task has shifted to learning how to think on your own, how to recognize work of quality when presented badly, how to spot glitzy work that has little substance, etc. Doing research at the "cutting edge" of your chosen profession is not something that just happens after having passed so many courses; you must learn *how* to do it. Not everyone is equally capable at research, but virtually anyone can benefit from learning how it is done. I'm not fond of sports analogies, but successful sports figures are not necessarily those born the greatest athletes; some have become accomplished in their profession simply through learning the basics and performing those basic skills consistently at their highest attainable level. I believe the same to apply to scientists and I will have more to say about how science is done, later.

D. On professors

I have mentioned the role of mentors in your career development. Professors seem like distant, monumental figures to many incoming undergraduates. It is common to learn, over the course of an undergraduate program, that these people who seemed so godlike at the start have feet of clay (like your parents!). I want to urge you to avoid going to the extremes of hero worship or contempt for professors. They are human beings, with weak points and strong points. The trick to developing a *productive* attitude toward authority figures like professors is to learn from *both* their good and bad points. Obviously, we can benefit from emulating the characteristics we perceive as good qualities in our mentors. However, we frequently overlook the value of *negative* role models. If someone has a trait you perceive of as negative, investigate it and be certain it is something you don't want to have. Often, upon deeper investigation, there are good reasons for why someone behaves in a certain way. If it appears, however, that there is nothing redeeming about some characteristic in your professor, then avoiding that trait in yourself can strengthen

you. Vowing to avoid bad behavior is just as valuable as promising to emulate good behavior. This information can be quite important during the course of your career. Some students grow up to be professors themselves, and many of them inflict the same mistakes upon their students that their professors made with *them*, simply because they never learned from the mistakes of their teachers.

E. Thesis/Nonthesis options for a Master's degree

It may be that at your institution, it is possible to obtain a Master's degree in what is known as a "nonthesis" option. This may be a reflection of something I discussed earlier: the Master's degree may be useful as a terminal degree for support staff who never intend going on to do independent research. Hence, a program that involves completing the coursework requirements for the Master's degree and some combination of extra requirements short of a thesis may be available. Depending on your career objectives, is this an option for you?

In general, my response to this is that it probably is *not*, unless you are absolutely *certain* that you do not want any degree in that field *beyond* a Master's degree. There are few absolutes in life, and taking such a degree usually means that further education in that field is going to be handicapped with the undeniable stigma of what is almost universally accepted as an inferior degree. There may well be some effort on the part of the faculty to avoid the appearance of a "cheap degree" in such a program, but it is very difficult to prevent the outsider from concluding that this was a graduate program that avoided something important.

Nevertheless, you may still believe that this degree is just what you want to do. You may want to have the extra coursework and are pretty confident that research is simply not your cup of tea. If there are no absolutes, then I cannot say with absolute confidence that you should *not* pursue such an option. You should be aware of your options, and if it is indeed an option at your school, then you need to make a conscious decision about its appropriateness in your case.

F. Special degree programs

As with undergraduate degrees, there may be specialized programs within your department available on request and subject to restrictions about who may qualify. Degrees in science or engineering with special emphasis on applications or with extra math and/or physics requirements are sometimes

offered. Dual majors or majors with special emphasis on non-major content are relatively common, and can be quite attractive to those who have diverse interests or a desire to qualify for certain employment situations. Sometimes such programs include a sort of work-study program sponsored by some organization outside the university as a way of looking at students and showing students about the jobs they might do. I have noted that being aware of your options is a good thing. Become acquainted with the programs your department offers and give consideration to some of the special things that may be available.

IV. Class time

A certain amount of the following repeats things I've already said in my book about undergraduate school. If you've seen it, I hope I will have some things to add that are of particular importance to graduate students. If you've not seen it, I will try to give the essence of the content I put in the other book, but it will be condensed to what I think is the bare minimum.

A. Taking notes and listening

In graduate school, the premium on listening is even greater than during your undergraduate days. If you find yourself taking notes furiously during the lectures, the odds are you're missing many of the points being made. It is time to get rid of the "stenographer" mode during your classroom time. Professors can be tough to pin down and class time is a time when they're guaranteed to be around. Use that time to your advantage: pick their brains and make sure they get through to you with the material they deem to be important. If your notes are neat and extensive as you walk out of class each day, then you're losing out! Keep your notes brief and write down only the key points.

Although the object is to understand everything that is said, *as it's being said*, there will no doubt be times when you don't understand something. By all means, get that hand in the air and ask the question! Don't depend on your being able to figure it out when you get back to your apartment to look over your notes. That professor is in front of you for an hour (or whatever) so get those questions answered right away. This brings up the subject of class participation.

B. Class participation

Apart from getting your questions answered, there's another important function that takes place in the classroom only if you really participate. You have not only the professor in front of you but also a group of peers around you. In graduate school, discussions among the class members might be more frequent than they were in your undergraduate days. Class sizes are smaller, so you tend to know a higher percentage of the folks around you than in undergraduate school. Open discussions might even be encouraged by the professor (the good ones, anyway). Your peers and your interactions with them may well be an important key to your education. Their questions and answers ought to assume greater import as the professor's oracular status diminishes. A good graduate level class, even in the physical sciences or engineering, can take on the dimensions of a discussion group, at least in the upper division parts of a program. If such an atmosphere develops in one of your classes, by all means dive right in with whatever opinions and viewpoints you might have. This can only be of benefit, and the only possible drawback is that sometimes, you might look stupid or foolish. If you're afraid of being wrong or of saying something stupid, then you should get out of the sciences or engineering, because it is only by taking such risks that you learn and achieve. Only mediocre professionals never do or say dumb things, and they achieve this by never doing or saying *anything* where they can't be guaranteed not to look foolish, ever. This leads to a rather meager set of accomplishments. Successful scientists and engineers get that way by making mistakes, not by being right all the time. So pitch right into these class discussions.

If your professor asks questions in class (a technique I favor, so I use it all the time) rather than pouring out wisdom, then you should be volunteering your answers, if you have any ideas at all. Of course, you shouldn't be saying things just to be saying them. Always piping up can be a form of "brown-nosing" and is easily recognized for what it is. Your answers should be genuine and if they can't be, then it's O.K. to not volunteer. If you have an idea, go ahead and say it; if not, then wait and see what happens. You may be "volunteered" by the professor to answer, even if you didn't ask for the opportunity. If so, give it your best shot or simply say, "I haven't any idea!" rather than blurting out just anything.

The main idea is to be involved in the discussion. This sort of interaction among peers is going to form an important part of your professional life and it's not a good thing for you to be a non-participant. Not everyone finds this to be an easy thing to do, but it is a skill that can be learned and your fears *can* be overcome.

C. Homework

I would hope that by the time you have gotten to graduate school, you have learned the value of homework. Not only does it give you a chance to think about problems without the pressure of having to respond quickly in class, but it also allows you to practice the skills you are going to need. If you think homework is a waste of your time, your time is certainly being wasted being in graduate school, but not because of homework! You need to change that attitude if you are going to have any chance for success.

In my opinion, you can never get enough homework, so I tend to assign a lot of it. If you haven't been assigned some, go get it on your own. Do the problems that were *not* assigned. Do all the extra credit problems. Think up interesting problems and try to work them out for yourself. And try to find someone willing to check out your work; if not the professor, find another grad student with whom you can interact. Yes, I realize this sounds rather crazy, but it's going to pay big dividends later, especially if you find you really enjoy the challenges.

D. Seminars

The word "seminar' means different things to different people. Generally, it means a sort of group discussion, usually supervised. This might be a group of students under the supervision of a faculty member doing some specific research project. A seminar also can be a set of formal presentations with ensuing discussion, perhaps by one or a series of invited speakers. It might even be a very informal group discussion with little or no supervision or focus. This sort of experience often is limited to upper division students, but if seminars are available, I want to encourage you to participate at every available opportunity. These discussions often are a place where you can learn to do the critical thinking to which I've already referred. For the enthusiastic graduate student, seminars can be a place where new and exciting ideas are encountered and tossed around.

In going to formal presentations, it is quite valuable to develop your ability to do critical thinking. Can you spot the difference between a poorly-done piece of work that has been presented well and a well-done piece of work that has been presented poorly? The substance of a talk is not necessarily associated with how glitzy the visual aids are. Some presenters are quite capable researchers but never learned the art of effective presentation. (Think that one over as you work toward your thesis defense!)

Think about what it means for a piece of research to be done well. What are the clues that signal a

valuable contribution? Get involved in the question and answer session that usually concludes such presentations; this is a good way to ferret out weaknesses in the work. Your career as a scientist or engineer is going to involve a lot of criticism, so you should be developing your skills as a critic. It might be useful to have a group of your fellow students involved in post-seminar critiques, at least informally.

E. Examinations

Exams are ubiquitous during classes. At their best they are designed for you to learn how well you have mastered the course material up to that date. At their worst, they are a means for the professor to punish you in some way. No matter what the intent, you need to approach examinations as a mechanism to gauge your progress; doing badly is almost certainly a sign that you have not done your job as a student. Of course, last minute cramming is a stupid, juvenile approach to studying for exams. Preparation for exams is simply a matter of understanding *everything* that you are taught, and *more*. Anything less ought to be unacceptable and, if properly done, exams take care of themselves with no further effort on your part other than what you should be doing every day.

V. Non-class time

A. Homework and studying

If you approach graduate school with appropriate seriousness, little needs to be said about devoting time to homework and other forms of out-of-class studying. This has an extremely high priority in your scheme of things or you will not make it. Mastering the course material given to you on a regular basis (each day) is simply a necessity. Anything less just won't get the real job done. You might make grades, but grades are no longer the real issue. It's time you realized that what you learn will be the basis for what you do the rest of your professional career.

B. Research

Since doing research is almost certainly a component of your graduate education, it will become a new and very special part of your non-class time. If your aim is to go on to do research yourself, this obviously is a critical component of your education. If your goals do not include research, you almost

certainly will be using research in your duties, so it is important to have at least some idea of what research is all about; this will not be wasted time!

If you have an assistantship, and you are allowed the privilege of doing thesis work in exchange for that support, you are certainly in a good situation. You wouldn't want to spit on the hand that feeds you; take your research seriously and make sure that you devote an appropriate amount of your time to it. Remember that when you are doing the work of research, it can be a real time-eater; in good situations, research is so much fun that it's hard to focus on more mundane things, like classwork. You need to stay focused on the whole program!

1. Master's level research

I've said that you may or may not be allowed to work on your thesis research as part of your assistantship, assuming that you have one. I'll get to the lucky few who don't need an assistantship later. Given that some one is paying you to do research, the next issue is to know exactly what is expected of you. The graduate catalog may spout some platitudes about how you should be able to combine research and coursework; the reality is that if you are taking three or more courses of graduate level work, you are going to find it quite difficult to devote much time to research. The course load is designed to be rugged, so I think it is reasonable to expect relatively little in the way of research productivity from new graduate students, at least for the first year or two of graduate school. If you manage to carry out some simple research assignments you will have done very well, indeed. I think that expecting more of yourself is grossly unrealistic. If your Advisor expects more, then you have encountered a particularly challenging situation and I can only echo what I have said earlier: if you survive it, you'll emerge all the stronger for it.

I believe that Master's level research needs to be *guided* research, at least for the vast majority of students. I'll have more to say on this later, but I need to get the essentials across now. Basically, what I'm saying is that the Advisor provides a research topic and an ever-decreasing but initially large amount of guidance about what work is to be done. Unless you are an exceptional student, if you find your Advisor turning you loose for extended periods and still expecting significant progress in the research, find another Advisor! The same goes for an Advisor who expects you to supply the Master's Thesis topic. The object of Master's level research is to show you *how* it's done, not for you to manage to propose and do original work on your own. Naturally, if you *are* an exceptional student, this will be a pleasant surprise for your

Advisor and he or she ought to be flexible enough to let you do as much as possible on your own, but never so much that you can't handle it. And your grades ought to be a good measure of how much you can handle in coursework. If your grades are poor, then either you need to be asked to leave graduate school, *or* much less ought to be expected of you in the research side of your education, at least until later.

Late in your Master's program, your formal course load can and should be cut back and a large fraction of your credit hours can be in official "research hours." This typically is when the work for the thesis research is being wrapped up and the writing of the thesis takes place. Note that virtually all graduate schools and departments have a deadline for turning in a finished thesis that arrives sometime well *before* the end of the semester. Check out the details of the requirements and deadlines within your own graduate school and department. It will take some careful planning and working with your Advisor to complete the work and write up the thesis to everyone's satisfaction (remember your Advisory Committee?) on time. And you will have to keep up your end of the bargain in terms of completing things expected of you according to your plan!

If you are *not* in the ideal situation of having your thesis work and your assistantship work coincide, then you are going to be expected to do some research work over and above what you do for your thesis, on a regular basis. Since this work will be the basis for your income, it's not something you can just blow off when times are tough. This is entirely equivalent to putting yourself through school while working part-time on some job. This will be no small feat; your obligated hours outside of class will have to include budgeting time for this research work in addition to your studies. Eventually, you'll be doing your thesis research *and* the work you are being paid for during the same term. Make no mistake; this will be a difficult road! As I've said several times already, surviving it will give you strength that most of your peers who had it easy by comparison will not even comprehend. Challenge is at the heart of graduate school and this will certainly challenge you. It's not impossible, but you will have to be very adept at time management to keep from letting other aspects of your life slide.

If you're independently wealthy or have a "no-strings" scholarship, then you still need to devote research time, but you no longer have the same pressure of depending on that research to support yourself in school. You're probably a pretty good student if you got this good a deal, so now the challenge is to make the *project* a challenge. A good advisor can always find an appropriate challenge level to suit your need to grow through overcoming adversity. This can be a very good experience for you, so you need to

take it seriously. In your case, you can take the first year or two to really focus on coursework, leaving the research to do in your spare time (like the summer, or between semesters, or during class holidays). Then, when your expected graduation date is about a year away, the time to accelerate the research work has arrived, and the course load can be reduced as described above.

2. Doctorate-level research

Whereas the Master's research goal is to teach you how to carry out research and to write up the results, the goal for Ph.D. research is for you to learn how to do *original* work, including: the formulation of a research problem, planning *and* carrying out the research to solve the problem, and (naturally) writing up the results. As before, I'll have more on this later, but I want to list the essentials so you can understand how to plan your time.

The formulation of original research is not something easily learned, and there is no simple algorithm to follow that offers guaranteed success. Your Advisor ought to leave you alone in this process; a guided Doctoral thesis is no more than Master's degree program repeated! However, this process is not easy to do, and you can expect to struggle with this as you go through your coursework. Time needs to be set aside for this effort and since there is no one path to a successful original research project, you should expect to go down some blind alleys before you hit on a promising path. What this means is that you and your Advisor should budget time and resources for this "experimentation" activity right from the start of your Doctoral program.

If you are still getting support from an assistantship at this time, it will be a trying period for all concerned. Chances are good you will feel frustrated and foolish and perhaps under some pressure to produce something relevant to the grant that is supporting you. Unfortunately, you probably are going to have to "waste" quite a bit of time in the process of formulating a research program that will lead to your Ph.D. (or equivalent) thesis.

In my case, circumstances forced me to give up my assistantship and I had to find some other source of income. It turned out in my case that this "disaster" (really, a well-disguised blessing!) occurred after I had completed the coursework requirements for my Ph.D. and so I could fill out my credit hours with "research hours" and go to work part-time to support myself. It was during that work that I hit upon my eventual topic. Believe me, I went through very trying times in that first couple of years of my Ph.D.

program, groping for a meaningful dissertation topic. From what I have seen, this is a common theme, so you should expect this anguish as a natural part of the process.

C. Extracurricular activities

As I noted in my book on undergraduate school, some time away from academics ought to be integrated into your plan. No one is more convinced than I that graduate school is the time for focus on your career studies, but ... you still need to get away from the grind periodically. Some physical exercise will do wonders for taking your mind off your studies and in addition to the health benefits (that allow you to be a better student!), you will almost certainly find solutions to problems that had been unsolvable before you took a break.

Some light participation in your hobbies will not hurt, as long as they don't demand a lot of your time. Whatever can get your mind away from your work is beneficial. Presumably you like to engage in your hobbies and other extracurricular activities, so this is good simply for its own sake. As with physical exercise, you will find that you are refreshed and better able to see solutions to tough coursework and research problems if you get away for a while.

The only danger is with hobbies that demand a lot of time, or participation at a set time. Graduate studies are simply not very forgiving of missed opportunities; anything that ties you up is potentially harmful to your career goals. This time, after all, is the best time to focus on what you are going to do for the rest of your career. Isn't it worth giving up (or cutting back on) some of those things, at least for a few years? If your bowling league, or glee club, or whatever, is too important to give up for your studies, then you really need to evaluate your goals. Mediocrity is a likely outcome of diluting the graduate school experience! Occasionally getting away from your academic grind is a good thing, but like most things, it can be overdone.

D. Friends, roommates, and the opposite sex

It probably won't require too much thought to guess what I'm going to say here, so I'll keep it short. As with extracurricular activities, your interpersonal interactions need to be done in moderation. I'm not advocating that you live like a monk, or deprive yourself of all human company in your drive to succeed. Far from it. Perhaps you need friends a lot more than ever during this period. But complicated

relationships (and most human relationships end up being complicated) offer extra challenges at a time when challenges are all too easy to come by. I recommend simplifying your personal interactions to the maximum extent possible. Although this is easy advice to give, it is not easy to do. My own experiences suggest that it is indeed *possible* to juggle rather complex interpersonal experiences (sorry, it's not necessary for me to provide the gory details) with graduate school, but it certainly makes for some difficult situations. I don't recommend it.

E. Special aspects of student life for married graduate students

Although my marriage didn't occur until I was writing up my Ph.D. dissertation, I knew a lot of married graduate students. In most of my experience, the spouses of my fellow students were not students themselves. What happened was that most of those marriages failed to withstand the strains imposed on them by graduate school. Many of the couples among my fellow students broke up before I graduated, and some of the rest followed soon thereafter. For the spouses of students, it's hard to cope with the obligations imposed by graduate work; the spouses often feel ignored, neglected, and perhaps *used* by their mates. Often, a spouse's income from a job is necessary to make ends meet and it is easy to conclude that a high price is being paid to support a mate's studies with relatively little short-term payoff. This can be really exaggerated when there are small children to care for and the spouse of the student gets stuck with all the childcare, housework, etc. so that the graduate work can get done.

It takes a lot to keep a marriage and family together through the rigors of graduate school. In any human relationship, a sure road to failure is for one partner to feel that he or she is "sacrificing" for the good of the other; *both* sides need to feel like they are "winning" or the relationship sours sooner or later. The price paid for by the one making the sacrifice will eventually be exacted from the other, so a graduate student needs to work out an understanding with his or her spouse *before* ever starting the program. And the spouse needs to know that the seeming indifference to his or her contributions and sacrifices is not what it seems to be. Graduate school simply imposes a huge set of constraints on the student and demands the vast majority of the student's time. The inability to give of that time is not a character flaw or a lack of commitment to the relationship; it's simply a requirement of the program. If the relationship is to survive this challenge, both parties need to understand what is coming and to develop some sort of an agreement about how to deal with the situation. It's not within my powers to offer specific advice about

how to do this; there are too many different situations and anyway, I'm not qualified to be a marriage counselor. But I have seen what I have seen and I think I can understand how difficult it is to hold a relationship together through graduate school. Success in a chosen career is difficult enough without having to cope with the stresses of troubled marriages.

VI. Graduate research

For science and engineering graduate degrees, research is really at the heart of the program. This generally takes the form of some sort of thesis as part of the degree requirements. It is expected that the student will participate in a project leading to the thesis; as noted above, this may or may not be the work that is providing financial support to the student. In any event, the importance of this effort cannot be overemphasized. For most graduate students, this will be the first forays into real research. As such, these first steps often determine the outcome of graduate education for the individual. Those that find the experience rewarding and stimulating (if not fun) will generally want to do more. Those that have a bad experience probably will go no further down the road to independent research.

A. Balancing classroom and research time

Generally, academic programs assume that you can carry a full load of coursework *and* do research at the same time. I've already suggested that this is idealistic nonsense for most of us mortal humans. Just mastering coursework is a considerable challenge at this level. If it's not a challenge, then either you're a certifiable genius or you're not taking an appropriately challenging program. If you are a genius, fine ... but most of you aren't. It is marginally feasible to carry on some of the more modest aspects of scientific research while focusing on coursework; perhaps weekends and holidays offer some opportunities, as well as during the summer. My personal advice is that if you are expected to carry a full load of formal courses *and* to carry out a full-scale research program, find another advisor, or another program at a different school! This is an unrealistic expectation. Toward the end of required coursework, it should be possible to reduce the formal course load and take a number of hours of "thesis research." It is during this "stretch drive" of a degree program that the research gets done. When reaching this point, you should be pretty focused on getting the research done.

B. During a Master's program

1. What's the goal of Masters-level research?

Master's level research is generally not expected to be particularly original or innovative. If it should be, of course, so much the better, but this is not a necessary component of the work. Oftentimes, the student is being employed as a "crank-turner" by the advisor, in exchange for which the student's work will be considered acceptable for a Master's thesis. You should keep the following in mind: Master's level research should be designed to get your feet wet, but should not be a total immersion treatment. In general, you are probably not qualified to define the topic of your thesis research. Topic selection should be the province of the advisor at this level and your task will be to carry out your advisor's program of study. Your advisor should expect you to be asking a lot of questions like "Why are we doing this?" and should be helping you to understand how to find answers to your questions. At the end of the program, at a point usually determined by the advisor based on your input, you should have a pretty clear understanding of the following:

a. What was the point of your research project?

b. Why should someone besides you and your advisor care about the results?

c. What procedures did you use, and why those particular procedures?

d. What data (and/or theory) did you use and how confident in its quality (and/or validity) should we be?

e. What results did you obtain?

f. What further work along these lines needs to be done and why?

Master's level research is not necessarily publishable work. It probably will be your advisor's choice to pursue publication of the thesis. If the thesis is not a deathless contribution to the annals of science or engineering, don't worry about it. If it satisfied your degree requirements, then it did its main job! Do not be satisfied with shoddy work, of course. If circumstances forced you to make some compromises that made you uncomfortable, make it a point to do better next time, but there is no cause for anguish when the work got you where you needed to be. A Master's thesis is primarily a learning experience; not every learning outcome is a happy or important outcome, but if you learned from it, then it

has fulfilled its main goal.

2. Who is a good bet to be your advisor?

It may happen that you have little or no choice about who your advisor will be. It also might be that you will be more or less free to choose your advisor. In either case, you should be wary if your Master's level advisor gives you a lot of freedom with regard to the research. Be especially wary if your advisor does not seem particularly interested in what you are doing. A really tragic situation can develop, where you are struggling to know what to do or how to do some task during the course of your research project and don't feel you can go to your advisor for help in getting going again. If you find yourself going in circles or going nowhere, don't hesitate to talk to your advisor about the project. If this sort of interaction is discouraged or not available, you should consider changing advisors. I have seen a lot of Master's level students "turned loose" without much guidance. This is usually a program destined to fail and the student will be the big loser.

Another dangerous situation is to find yourself being used by your advisor for his or her own purposes. In such situations, the program can drag on for years, with the advisor getting low-paid help while the student goes nowhere. I have seen such situations, even when the advisor's intentions are not evil. A Master's degree program should be complete within three years or so. Any longer than three years is a sign that the process is going astray somewhere. If your intention is to graduate and move on to other things, but the situation is bogged down one way or another, then you need to be considering your options, up to and including getting another advisor.

Something to think about also is the issue of simple personality clashes. Not every matching between advisor and student is going to work, irrespective of everyone's best intentions. Advisors are humans, and they have real personalities that may end up not suited to you and your situation. In such circumstances, it might be good for all concerned to switch advisors. Perhaps you have already identified someone else on the faculty with whom you seem to interact more effectively than with your current advisor. You could also seek help from the department chair or the faculty-student representative in such situations. Generally speaking, these "divorces" may not always be amicable, but they usually are in everyone's best interests.

Although I have focused on the negative situations for the simple reason that the positive situations

require no adjustments, it is best for your interests to work as hard as possible to make the best of a situation that is less than ideal. Generally speaking, unless your program is dead in the water and not likely to move forward, you can survive most of the situations that will develop during your program. A student who creates problems for the department usually creates problems for him- or herself; it's better to go on and complete the program and then vow never to get into such a situation again, than to create a furor unless it's really necessary. Remember that *graduation solves a lot of problems*; finishing is the goal and if you are constantly searching for an ideal situation, you can prolong your stay in the university way beyond your best interests. If you made a mistake or two and survived them, then those mistakes actually made you a stronger person.

One final note, here. Not all your problems may be external. Your advisor may be doing all he or she can do, but you are still slow in finishing up. Some students take a less-challenging course load in order to ensure relatively high grades. This can have the effect of dragging out a degree program. I've already mentioned this; if you're intentionally slowing down the process for no real reason, you're short-changing yourself. Moreover, another reason for having problems during your Master's program can be simply that you are not really up to the challenge of graduate work. I don't want to introduce more doubts beyond what you may already have, but that has to be an alternative you might need to confront. I am not capable of making that judgment in this book.

C. During a Doctoral program

1. What's the goal of Ph.D.-level research?

I've noted earlier that whereas the Master's thesis research should be *guided* work, the doctoral dissertation should be done as independently as is possible. Doctoral theses ought to be original, creative, innovative, and publishable. If you accomplish anything less than these goals, then your work was wasted even if you graduate. It is presumed that a Ph.D, scientist or engineer is a problem-solver, knowledgeable about what has been done in the sub-field of choice, aware of what needs to be done, and capable of advancing the field. Knowing what to do; i.e., choosing a topic, is perhaps the most challenging thing confronting a Ph.D.-level graduate student. A suitable topic is simultaneously (a) worth doing, and (b) capable of solution. There are many problems that are one or the other, but not both. Unsolved problems are unsolved perhaps because they have so far defied solution. If you think you can find a solution, that

sounds like a pretty promising topic. Many problems that can be solved are not very interesting or useful. Your task is to find a topic that is solvable and worth solving. Finding such may well be a real struggle. You may have several false starts that simply lead nowhere. Your first ideas may well not pan out.

This process necessarily draws on your coursework. A lot of coursework in science and engineering is designed to take you from point A to point B. How many times have you been asked to start somewhere and derive a certain result? This is problem-solving, but the problem and the outcome have been mandated in advance. Once you graduate, you will be expected to solve problems that may be of your own choosing. They must be original. No one will give you the starting point, and it will be up to you to know when the problem has been solved. The techniques you learned during coursework provide you with tools that are needed, but it is up to you to define problems to which the tools are to be applied. And you will be expected to defend your ideas along the way. This process is not easy to learn, and I know of no simple formula to give you that will make it easy. If I could, I wouldn't anyway, because that formula might not be as good as the one you will come up with on your own. For most Ph.D. students, the dissertation is your first foray into this part of the research world. It is very important that you find your own way through. To graduate without finding your own path to the dissertation is to graduate a cripple. Most folks hiring Ph.D.s don't want to support them while they learn how to do research; they want someone who can start out right away on their own, independent research.

2. Who is a good bet to be your advisor?

Most of the properties of good advising for Master's-level work are the opposite of what is needed for Doctoral-level work. A good advisor for Ph.D. dissertation research is one who provides a great deal of autonomy for the student. The topic should be the student's, of course. How do you as a student know when your topic is right? If your advisor *tells* you whether or not your topic is suitable, then your program is well on its way to failure! What your advisor should expect from you is for you to tell him or her that the topic is going to be your dissertation topic, and you should be prepared to justify that choice in ways that make sense to any scientist (or engineer, as appropriate). The same goes for when the work is done; you will have decided it's done and you will be prepared to demonstrate that in a convincing way.

I can't claim to have seen every successful doctoral program, but I have observed enough to know that there comes a point in the good situations where the student, who has struggled with the topic and then

the work itself for quite some time, suddenly sees the way to complete the process. A good advisor can recognize this, too, and will be supportive in the effort to convince the student's committee that the dissertation research has been completed. Often, the advisor will be interested in helping the student publish the dissertation. Personally, I'd be worried if the advisor is *not* willing to co-author a formal, refereed publication based on the dissertation!

To the maximum possible extent, the relationship between you and your advisor must become collegial, not that of advisor and advisee. Certainly it will begin as advisor and advisee, and it is not possible to forget that as you make your progress. In the same way that you never quite convince your parents that you have become an equal, because they remember changing your diapers, your advisor probably never will be able to put your advisee status completely out of his or her mind. You may never be comfortable addressing your advisor with a first name. No matter. Remember that you are striving to attain an ideal situation that is virtually certain never to happen, but you have to achieve independence during your Ph.D. program. Regardless of how your interaction with your advisor turns out, you should be able to achieve this independence along the way, or you should be seeking another advisor.

D. How research gets funded

I am spending time talking about this, not so much because you need to get your research funded (although, of course, you may need to do so someday), but because of the impact it has on your relationship with your advisor. Basically, most research gets funded through writing proposals to do the research, with the proposal being considered for financial support by some funding agency (like the National Science Foundation). Once the research gets funded, the professor seeks some student to help carry out the research. The work might involve simple "crank-turning" (i.e., Masters-level students), or it might require innovative thinking (i.e., Ph.D.-level students). If you are working on a Ph.D. and you become that professor's advisee, it is in his or her interests to see you carry out a specific set of tasks aimed at achieving the results for which the proposal was funded. Do you see how this might be a conflict of interest? It is in *your* interests to carry out research purely of your own choosing, where you have to struggle some to come up with a topic.

It might seem like an easy compromise to make; simply to carry out the work that your advisor wants you to do. In fact, you could find that work interesting and challenging, but stepping into such a

situation will not necessarily be in your best interests. Of course, it makes completion of your doctoral program rather easy. This might be of some value, if there is something you want to pursue once you graduate.

Nevertheless, there is some difficulty with reconciling the needs of the professor with a funded proposal with the needs of a student to develop a sense of independence. This conflict leads me to suggest a somewhat unusual approach to selecting doctoral program advisors: it might make more sense for students to avoid professors who specialize in the topics that they (the students) want to pursue! This is, I believe, somewhat contrary to popular wisdom in this arena. In my own case, my advisor was working in a field related to my eventual dissertation topic, but he was more than willing to support my research. In fact, his Ph.D. graduates did dissertations on a wide range of topics, only a few of which coincided with his own interests. Retrospectively, I think this was a sign of an outstanding advisor, who was willing to let his students follow their own paths. His funding situation was such that he could afford to do this and still keep his funding agencies happy with the results of their support. In my case, my last semesters were funded on my own, without the financial support of my advisor. This turned out to be a real blessing for me, as I no longer felt any guilt about taking his support while doing nothing he could use to justify that support.

In summary, then, as a potential Ph.D. student, you are going to have to be careful not to be subverted by a conflict of interest between you and your advisor. The simplest path is to do what your advisor is getting support to do, but unless you helped obtain that support for your proposed research, the danger is that you will not develop the independence you are going to need.

E. Department Politics

Department politics are a trap for the unwary graduate student. Obviously, it is just plain foolish for a student ever to get involved in them, and yet students do so. Perhaps it is natural for idealistic students to take sides in some departmental conflict, but I want to be sure to tell you that this is not a good thing to do, at least by choice. There are times, of course, when students become involved in one way or another without any intention of doing so. Perhaps your advisor, who is warring with some other faculty member over something, wants to bend your ear with his/her story. I think it is appropriate to say, when encountering this, something like " Professor So-and-So, is this really any of my business? How is this

going to help me in my academic program?" It might be unlikely that you would say something like that, though. Maybe the best thing to do is listen to this sort of harangue, but do not allow yourself to be caught up in it. A good advisor does not involve students in the squabbles that inevitably arise in academic departments. A smart student stays out of those squabbles; getting caught up in one as a student is a formula for academic disaster. Students are more or less without any power or authority in these conflicts and can be seriously damaged by taking sides, no matter who is the "winner" between the factions.

VII. Graduate exams

As with your undergraduate days, there are course examinations, but course exams are not the topic of this section. Those should be familiar to you by now. Beyond coursework exams, it is typical for there to be various sorts of formal examinations at stages during graduate school. These exams take many different forms and it's in your best interests as a student to know precisely what will be expected of you in your department's exams. All these exams are hurdles that must be cleared on your graduate degree path.

A. Qualifying exams

It may be that you need to pass a "qualifying exam" (or "general exam") at some point during your Master's or Ph.D. program, or both. These often are comprehensive exams focused mostly on the topics of your field. They are nominally designed to see if you have enough knowledge within your field, although the degree to which they succeed in this goal can vary a lot. Often, such exams can be spread out over more than one day, and will be composed of several component parts. The questions can range from being more or less like typical course exam questions to being far more open-ended. Grading can range from being mostly objective to being quite subjective.

Typically, one must pass this exam at some minimum level to proceed to the next phase of graduate study. I believe that the best advice I can give you is to not spend a great effort in studying for these. There are arguments I have heard that studying for these is a way for you to pull together all the disparate parts of the courses you have taken. I disagree with this view; rather, the development of a coherent understanding of individual course content should be happening as you go through each semester. I am not convinced that any understanding you might generate while studying for

comprehensive exams is going to be a very permanent fixture in your view of your field. Cramming is cramming and it mostly stays in short-term memory, to be flushed when the exam that forced it has been passed. Cramming is not an effective way to learn the content of what is going to be your profession. Nevertheless, I am reasonably confident many of you will do so in spite of this advice. The concepts you are supposed to have learned, over which you are being tested, are going to be the basis for the rest of your professional career. Cramming them in shows you are not really serious about learning them.

Another viewpoint on these exams is that since they simply are another stepping-stone to be crossed on your path, they are not worth spending a lot of time agonizing over; if you pass them, then you can move on to other things. Is the level at which you have passed them important? I really don't think so, unless the level of passing has some direct bearing on how you proceed. Again, I repeat that you need to understand what is expected of you on these exams. If they have some meaning beyond pass/fail, then by all means take them as seriously as that meaning warrants. If not, and passing at the minimum level is all that is asked of you, then why bother trying to do more? Obviously, if your mastery of the basic topics in your field is what I hope it will be with the study plan I have already described, then you should be able to pass at more than the minimum level with virtually no studying! But if it should turn out that you just barely squeak by with a "pass," is that going to matter after you graduate? I hardly think so. I am not a believer in spending a great deal of time worrying about these exams, as I think you should be able to tell.

B. Thesis/dissertation defenses

Virtually all programs involving a thesis/dissertation require you to defend your work, usually by means of some sort of presentation, followed by a question-and-answer session. The audience may be limited to your advisory committee, or it may be open for at least part of the time to a general audience.

First of all, if it is possible for you as a student to attend thesis defense presentations, by all means do so! Go to as many as you can cram into your schedule. This is a strategy that enables you to get an idea of what the process is going to be like, and to see how your faculty members approach the thesis defense. It is especially useful to see your advisor and your advisory committee members in action. It is not cheating to have an idea of what to expect, both in general and in particular.

Thesis defenses are similar in content, though not in duration, to formal presentations of your work that you almost certainly will be doing for the rest of your scientific/engineering career. The effort

expended here to do a good job is most assuredly not wasted! Going to as many defenses as you can before you have yours is also a good way to avoid the dumb mistakes that other students make. Developing good communication skills is going to be of value to you for the rest of your career. I will have some things to say about this in an appendix, so I will not elaborate here. For many of you, a thesis/dissertation defense will be your first chance at such a presentation. It is important that you do well at this, not just for the sake of passing, but also for the rest of your professional life. Take the time and do the "homework" necessary to get it done right. Learn from the mistakes of others and avoid obvious pitfalls.

C. Oral exams

Thesis defenses are heavy on the oral component, but there are exams of various sorts that involve an oral aspect. Most students fear oral exams, and I think I know why. Being able to perform "on your feet" is mostly a matter of two things: 1) mastery of the relevant knowledge, and 2) confidence in one's ability to perform. These two things are related; if you truly have mastered some knowledge, then you will have confidence in your ability to call on that knowledge when you need to. In fact, these factors are associated with success on any examination, not just oral ones. In oral exams, it is not uncommon for a student to get flustered to the point where he or she can barely remember the most elementary concepts in the field. This catastrophic outcome can a direct outgrowth of the failure to master the knowledge needed, or it may simply be the result of sadistic committee members. I will not dwell on the silliness of some faculty members who insist on humiliating students just for the fun of it. However, real mastery of your subject matter involves testing of your knowledge level on your own, before you ever go into a formal exam. This might be as simple as discussing the material with your fellow students, or it might be as artificial as giving yourself a "test" to see how well you can do.

As an example, at one time, I reviewed some elementary material and then closed the book to see how well I could reproduce the arguments simply by reasoning them out. It was frustrating and disconcerting to see how poorly I did, and it took a considerable effort to get to the point where I could start from scratch and derive the textbook results. However you do it, confidence that can withstand oral questioning usually comes from having tested your mastery of the subject matter. Oral exams will be no problem for you when you have done this. Until then, you will find them fearful and intimidating. There

will be lots of oral "exams" in most professional careers in science and engineering, but what will be at stake then will not be a grade or even a diploma; your success in your chosen field will be at risk. Getting good at oral presentations and surviving the Q&A that usually follows should be your goal, not some silly grade, of course.

VIII. The thesis/dissertation

The thesis (or dissertation) is one of those things that really separates graduate school from all academic activities you have done before. It is not just a sort of "super-theme" like what you have been doing for years. It is, as already noted, your introduction to the real process of research. Writing out your results is a critical part of the accomplishment of the research, inseparable from the research. Results not communicated to someone else are useless results, by and large. Understanding this is a critical part of your learning process during graduate school.

For a Master's degree, if you have indeed been the beneficiary of a lot of guidance during the process, as I have indicated you should be, this will also be a process that includes a lot of guidance. Although you may be asked to take a stab at writing a first draft of your thesis without much help, you probably will need considerable assistance. Good scientific writing is not something most of us did right away! If you feel overwhelmed, just go ahead and do whatever you think is right and don't be ashamed if it needs a lot of revision. Chances are your advisor *expects* that to happen.

If for some reason, you have not had much guidance, then I am sorry but the same lack of direct involvement is almost certainly going to continue as you write up the results. I just hope that if you ever reach the status of being an advisor to a student, you won't repeat the mistakes committed by your advisor!

For most Ph.D. students, you will have already done a Master's Thesis, so you should be able to get started writing without too much difficulty. In fact, at the Ph.D. level, the write-up should be the simplest part.

A. Some things to do

Even though it is going to be some extra work, I recommend keeping a sort of journal, or "diary" of what you have done during the course of the research. Write down your assignments, summarize the results of discussions about the work with your advisor and the members of your advisory committee, put

summaries of the results of each step along the way in your journal (especially in the form of tables, figures, etc.). All the entries should be dated. The idea is to have a record of what you did along the path of your research. This will pay many dividends when it comes time to write your thesis/dissertation. When a project stretches out over many months, or perhaps a year or more, it is not at all uncommon to forget things that happened along the way. A journal provides a valuable reference for your discussions with your advisor, who probably has other students and is almost certainly not going to remember all the details for you!

It is quite useful to write down questions in your journal about the research as you go along. And leave some space to allow you to insert the answers to your questions, if you find them later, either as part of the research or by getting answers supplied by people to whom you addressed your questions (e.g., your advisor, members of the advisory committee, other faculty, even other students). This journal will allow you to see a clear picture of the course of actual research. As I will discuss later, most of the contents of your journal will not go into the thesis, but your journal should enable you later to know what should and should not be included. As your career proceeds, you may or may not continue to keep research journals, but this exercise will be valuable to your development as a student, at the very least.

Another thing to do is to make it a point to consult with all the members of your advisory committee on a regular basis. Make appointments to visit with them and to share the results of your work as often as you need to in order to keep them informed. If your advisor prefers to be secretive and uncommunicative with the rest of your advisory committee, then either get a new advisor or be sure to let the committee members know that this lack of communication is your advisor's choice, not yours. The committee can be very helpful in providing fresh viewpoints and even useful ideas to pursue, but even when all they do is listen to you talk, at least there will be *no surprises* for them as you finish up. The results of your work might well contradict their work, or at least be contrary to their dearly-held notions. When that sort of conflict arises, it is best that it not happen at the end of your degree program, with deadlines facing you. Committee members who are unpleasantly surprised by your work are unlikely to be *cooperative* committee members at the end.

If you are working on a guided, Master's-level project, be sure that you are being clued in on what the project is all about, and why you are doing it in a particular way and not some other way. At the end, it will be expected that you can offer a coherent defense of the work without asking your advisor to help out

in that defense. Your advisor may or may not make all this clear without your asking for it, but why take a chance? Ask questions! Why is this work important? Who cares about this work? Where within the whole field does this work fit? Are the methods sound? Would other methods have done as well? How did the methods get chosen? Where did the data come from? Who vouches for the data? What quality control checks were done on the data? Are we sure that no errors are present in the data? What makes us so sure? What do the results mean? If the results are mixed (as they usually are), how do we interpret those results? What justifies that interpretation rather than some other interpretation? What is the applicable theory behind the methods, data acquisition, and interpretation? What assumptions are associated with that theory? What justifies those assumptions? And so on and on ... .

For unguided, Ph.D.-level research projects, all of the above apply, except that you are going to be expected to answer most of them on your own. This is your chance to do research the way *you* think it should be done, and to defend those choices in front of a group that will include real, functioning professionals in the field. If there is some doubt in your mind about any aspect of the work and it is remotely possible to do something to resolve that doubt, then *do it*! It's impossible to think of everything, but if *you* can think of it, the chances are good that someone else will. Mistakes made in ignorance are forgivable, but mistakes made by neglect or laziness will not be tolerated well.

B. When do you start writing?

For guided, Masters-level work, this decision should be largely in the hands of the advisor. Therefore, in such case, you simply need to follow directions about when to start writing. Most of this section, then, is directed to Ph.D. candidates. As noted earlier, the Ph.D. student is not only expected to select a suitable topic, but to carry out the work and to know when a suitable result has been obtained. Unlike going from point A to point B, the object here is to know where to start (point A) and when to stop (point B). This is the major challenge confronting those doing original research as professionals, so this choice is an important one.

For certain types of theoretical research, it may be fairly obvious when a stopping point has been reached. However, working with real data to solve real problems invariably involves a lot more than one originally planned to do. All sorts of side topics seem to crop up and some of them need to be pursued, whereas others need be left alone. It is these that seem to make settling on a stopping point so difficult. If

one simply proceeded stepwise from the idea to the work to the confirmation of the idea, research would be relatively easy. In dealing with *real* research work, things virtually never go that smoothly. Look over the journal you kept as a Master's student; did that work go directly to an obvious conclusion? Chances are there were blind alleys, surprises, re-thinking of major components of the work, and so on. There was a lot of work done simply to account for potentially obvious solutions to the questions being posed in the original idea; if something obvious could not explain a particular result, then new ideas had to be conceived.

Moreover, real research often turns up aspects of a problem that simply were not anticipated. Some of these need to be explored. Others definitely need to be left aside and perhaps returned to on some other project. Many these topics that turn up are neither obviously important nor obviously irrelevant, but rather fall into a sort of "gray area" that requires you to pursue them long enough to allow you either to go ahead and resolve them, or to put them aside as not pertinent. In doing this, it is assumed that you, the individual researcher, know enough about your field (and even related fields!) to be able to make these decisions. Here is where the long, extra hours put in during your coursework can begin to pay off! All those extra credit problems and readings that were not assigned but left to your discretion can be of tremendous value here. If you sloughed them off during your coursework ... well, the consequences of that might be critical here.

In my experience, the conclusion of a student's Ph.D. research project comes when that student suddenly recognizes "It's done!" That recognition often comes as a sort of epiphany, culminating many months of toil that seems endless. If you do not recognize that your research has reached a logical conclusion, then it probably is not yet done. If you cannot convince yourself that the project is complete, then it will be quite difficult to convince your advisor and the rest of your advisory committee! It still might be difficult to convince those others, of course, but you will not succeed if you yourself are not thoroughly convinced. Knowing you are done with a crystalline certainty is a prerequisite to completion of the work and the commencement of writing.

If you have followed my advice and have a well-maintained journal, turning to the writing will be a relatively simple task. If you have not kept a journal, I hope you have kept a clear mental picture of the project as you went along, including revising your expectations of the work as you learned new things from the project. If you have reached what you think is the end of the research project, a good thing to do

is pause and reflect on what you have done. Jot down, either via an outline (recommended) or as a disconnected pile of thoughts (not recommended), the highlights of the work, starting with the original idea, a description of what you did, and summaries of your findings. Obviously, here is where a journal would be handy, but if you are not the sort who does that sort of thing, you can still be successful in pulling your ideas together. The basic task is to develop a coherent "story" that will become your thesis, however you accomplish that.

C. What to put in and what to leave out

Whether or not you have a journal, it is likely that you will have done a lot of work that turned out to be simple "confirmation of the obvious." That is, you did things to convince yourself that obvious explanations for the results could be ruled out, or that some parts of the work simply reflected things that already are well-known. This work is most definitely *not* to be included. A good thesis is one that focuses on the telling a "story," as I have just noted. There is no need to include everything you ever did. A repetition of the contents of your journal would be an awful thesis. The readers of your thesis do not need to know about every blind alley you followed, every stupid mistake you had to go back and correct, and every revision of your expectations. To include all these things is quite typical of student theses/dissertations, of course. After all, you did a lot of work and you want everyone to know about it. The problem with that is the thesis ends up being an encyclopedia! Learn to think about scientific and engineering papers in terms of story-telling.

An important part of story-telling in your thesis concerns setting the stage. If you can't convince your reader very early in the story that the rest of it is worth reading, then don't be disappointed if no one ever completely reads your papers. Therefore, you need to establish early on why someone should be interested. What unsolved problem did you solve? What can we now do that, prior to this work, we couldn't do? Where does this work fit within the overall goals common to the field? Doing this right away establishes a sort of rapport with the reader that encourages a careful reading of your thesis. And you *do* want your thesis read carefully, don't you? If you are hoping no one notices the little glitches and problems that you know the thesis contains, then you shouldn't have given it to them to read, right? Fix any fixable problems you know about *before* you turn it in to your advisor.

In general, readers want to know enough about what you did to satisfy themselves that the work

was done properly. If a reader cannot obtain enough information from your thesis, either by its content or by the content of your references, then you need to add whatever is needed to bring readers to that point. A careful study of your thesis should allow anyone knowledgeable in the field to reproduce your results. Anything less is simply unacceptable.

IX. Getting finished

A. Decision time - a Ph.D. or not?

For those of you reaching the end of your Master's program, a big question confronts you. Should you go on for a Ph.D. or not? I've already indicated that the answer to that depends on your particular field's requirements at the level where you think you're headed. Whatever your decision, however, I want you to consider a couple of things.

1. Masters-level "burnout"?

A lot of students tell me they don't want to go to a Ph.D. because they're "burned out" at the conclusion of their Masters program. Personally, I find that a pretty lame statement, but perhaps it might be true in a small minority of cases. The reason I find that such a lame excuse is simply this: if you find the labor of getting knowledgeable in your chosen profession so much like "work" rather than "play," then perhaps you should consider another career. How can doing what you want to do for a couple of years burn you out? If it can burn you out in two years, what is it going to be like after 20+ years? Most of the "burnout" I see is a lack of clarity with respect to what a student wants to get out of the process.

2. It will never get any easier

Another thing I hear is that students want a "break" from school (along the lines of burnout), and that they'll be back in a few years. My experience is that most such promises are self-delusions, at best. If you've been a student, you almost certainly are broke all the time, and have been treated like scum for years. The unfortunate reality is that students are usually broke and treated badly; if you get out of school for awhile and work at something resembling a real job, you may get used to some decent pay and some modicum of respect and never want to go back to lowly student status. I think I can relate to that feeling, but if it means you are going to settle for less than what you might be able to achieve with the next level of education, then this is a really unfortunate outcome. In fact, it's an outcome that you might well live to

regret ... a lot.

An additional consequence of getting out of school for a while is that responsibilities tend to increase with age (i.e., time), so that you might well accumulate such responsibilities as a spouse or children. These additional responsibilities often lead people to being unwilling to live like students (i.e., broke all the time). Is it ever going to get any easier for you to go on to a Ph.D. than it is at the end of the Master's degree program? I think not. If you are ever going to need that Ph.D., you really should consider going on ... now, not later. The choice is yours, but think it over carefully.

3. The perpetual student syndrome

Some students end up taking forever to finish graduate school. Many times, the reasons for this are complex, but they generally relate to not having any clear goal of accomplishment to impel them along. It is possible to delay having to make decisions by the simple artifice of not graduating. I almost certainly am wasting my time, but I hope to suggest that "no decision" is really a decision. Not finishing means you are not going on to accomplish something with your career. Either you want to do something in the field, or you don't. If you don't, I want to suggest that you admit that and go on to some other career where you would be motivated to finish what you start.

Of course, there are other reasons, including things like writer's block (getting the thesis done) and having to reduce costs by taking less than a full course load because of inadequate finances. There are no simple generalities, but if being a student wasn't so unpleasant (poor pay, low respect, stupid university bureaucracies, etc.), it would be necessary to *make* it so in some way simply to urge students to move on. Hopefully, for you there will be no external reasons to delay your graduation. Some students seem to take a perverse pride in their ability to avoid completing their programs; I suspect a lot of this is simple posturing to cover up for their lack of will to do something with their lives. Don't emulate them! The idea is to finish your education so you can *do* something. If that's not your goal, have the grace to call it quits and make room in the program for someone who wants to accomplish things.

B. Job-hunting and the import of having a job waiting

Although there are no guarantees, in my experience, most faculty are willing to support whatever it takes for a student to graduate if they have a job waiting for them. The university tends to look bad if a

student fails to graduate when expected. Therefore, I really recommend being serious about seeking employment as you near the end of your academic program. This book cannot pretend to offer a thorough guide to employment in your profession; I couldn't possibly know all there is to know about your chosen field. I'm not sure I could do so even in my own field.

However, there are some things you should know. First and foremost, a career choice doesn't necessarily mean much specific about jobs. You can be a scientist and have many different types of employment: university positions, government laboratories, working for private industry, etc. Engineers can work in a similar range of situations. If you are going to have to make some choice of employment at graduation, it is not necessary to make a choice for all time. That is, you might well start out in some direction, and then decide after a couple of years that it was the wrong direction for you. No matter how much pre-graduation effort you put in on studying opportunities in the field, there is no way to be completely certain. Be flexible in seeking employment. Don't lock yourself into one path right away.

Hopefully, you have used your scholastic time to pursue opportunities exploring what your field is really like. Summer jobs, part-time employment, and so on can give you a chance to see what people really do in your field. Even if you have a really awful experience in such a sample, you perhaps will have learned that there is at least some part of your field you definitely *don't* want to pursue. There is always the chance you'll just love what you saw and that will make you all the more motivated to finish up and get on with the real work. If you haven't done any of this exploring in your field, then you will have to do it post-graduation, with a lot more at stake. I recommend taking the time to do this exploring as a student. It certainly will help in job-hunting, as I will discuss shortly.

C. Job interviews

There are whole books written about job interviews, but I think I can reduce a lot of the content to some pretty simple ideas. Much of this is also said in my book on undergraduate school, so I will try to keep this short. You should take job interviews very seriously, and not do anything stupid to jeopardize your chances with the interviewing agency. Wear clean, decent clothes; formal wear is almost certainly not necessary, but don't be slovenly, either. Don't go to an interview right after three sets of tennis on a hot summer day; be cleaned up and generally presentable.

An important thing to remember is that the interview process ought to be a two-way street. They

are looking at you, but you should be looking at them, too. If you have some goals, expect to be asked about them, and be prepared to expand on them if asked. Remember that being truthful is really important; *don't try to say what you think they want to hear*, just to get hired. Is being hired on false pretenses a good way for you to start your career? I really doubt it. A successful outcome to an interview it *not* that you get hired; a successful outcome can include a mutual agreement between you and the prospective employer that it would not be best for you to work for them. Being hired into a job that you end up hating is not a good outcome to an interview.

By no means is retirement an irrelevant topic, but you should be considering most seriously what you intend to do during your employment, not what you will be getting from them during your "golden years." Most of your concerns should be on opportunities to do something important with your education, chances for professional advancement, and with such things as training for the specifics in your actual job. You will be quite likely to impress your prospective employer if you have a genuine interest in achieving something, the more specific the better.

It is not uncommon for there to be more than one interview before a job offer is made. Be prepared to have one interview early and then go through another as the list of candidates is pared down. If you have made the "first cut" then consider it a good outcome; that employer might well be interested later, even if you're not the object of the first offer, so don't be too disappointed if you end up not being offered a job right away.

D. Your transcript's role

Some of you might be laboring under the misconception that if you don't have all "A's" or near it, then you don't have much of a chance in the job market. It is possible that some employers would consider that to be so, but not many of them. There is at least one reason for an employer to be concerned about a really high grade point average in your transcript: it appears that you weren't challenged during your academic program. And of course, graduate transcripts are usually all A's and B's anyway, so a 3.+ GPA is pretty much commonplace, which employers recognize. If you have virtually all A's, then there are some negative possibilities: 1) you took mostly easy courses, 2) the school where you went gave out high grades to nearly everyone, 3) your academic program was done with a one-dimensional focus and you had to live like a monk to achieve that transcript.

What I'm really saying involves two recommendations. First of all, I want to encourage you to take risks in your course selection. Go ahead and challenge yourself, and don't be disappointed if in the process you have failed to get the top grade. Knowing your limits is not a trivial benefit from taking on material where you could fail, or at least not excel.

Second, I hope I have offered some indications that it is useful to explore what real practitioners in your chosen field do on the job. If you have followed this suggestion, your transcript only describes a fraction of the experience you can offer to a prospective employer. I think I can guarantee that having positive references from someone working in your field besides the staff of your university will be a big advantage for you over those of your peers that have only a glowing transcript to offer. A transcript can be a very ambiguous and uninformative document for making job selections, so the value of these references cannot be underestimated.

A good employer can even find a not-very-glowing transcript intriguing. If the interviewer asks you questions about less-than-exciting grades a point of curiosity, take heart! If there are good reasons for why you got a poor grade in a particular course, the fact of the poor grade may not be fatal in your search for a job.

E. Coming back after being out of school

Being out of school for a time before coming to graduate work is by no means a handicap. If anything, provided the time off has given you a chance to think it over and come to a firm conclusion that graduate school is for you will be a help, not a hindrance. If the time off has been only a few years at most, then your student skills will return quickly and within a semester it should be more or less as if you had never interrupted your academics. I had a situation develop where I had a gap of about 2 1/2 years out of school and it was not a problem to get back in the swing of things. For that short a time away, student skills should be back in full operation by the end of the first semester back.

Although I can't speak from personal experience, it appears that if the absence from academics stretches out beyond five years or so, the situation may not be quite so easy. In my opinion, if you want what graduate school has to offer, it should *never* be too late, but I have seen some who try to come back after being gone for a long time and they have a tendency to defeat themselves. They talk themselves into failing even though they seem more than capable of confronting the challenges. I've already said that

graduate school is not supposed to be easy, and if you approach it with a defeatist attitude, you will not be disappointed, because it can defeat you. But if you confront each challenge, even after having been out of school for many years, there is no objective reason for you to fail.

Obviously, if you have had an extended absence, you may be returning with a lot of responsibilities to a family. Moreover, the financial problems may be substantial, since mature people tend to have more material things that drain their financial resources (cars, homes, children, etc.). These are ready excuses to falter. The choice is clearly yours; presumably, you have some personal reason for wanting to return to graduate studies. If that is a *good* reason, then you can find a way to overcome these obstacles. I certainly don't intend to repeat what I said earlier about the challenges that can confront a mature student with a family, but don't let your family responsibilities be a barrier to your achievement. It is possible to turn these challenges into a plus for you. If your family supports you and what you're trying to do, then that support can help you through the difficulties you will confront. If your family is opposed to what you want to do, then I have no simple answers. Perhaps you need to work with them to make them understand how important this is for you and, therefore, it should be important for them. Family opposition is no simple matter, and I can only say that you need to deal with it before you consider a return to graduate work, because you don't need, and can't afford, the energy drain that family opposition can represent. My main point is that the added "burdens" of mature students with families need not be a barrier to a successful graduate program. It can be done, and I've *seen* it done, so don't use that as an excuse.

X. Final thoughts

Appendix A. Writing a thesis/dissertation

It often turns out for many students that writing the thesis or dissertation is the most vexing challenge of their graduate careers. Although some students take readily to this task, for many of us in science and engineering, we have not necessarily been all that enthused about learning how to write. I am not about to offer a simple formula for success in writing, but I can provide some tips that might be of some help in the process.

1. Read the theses/dissertations of the school's graduates

It is a simple thing, but you may not have any clear idea of what constitutes an acceptable thesis (hereafter, the term "thesis" will be understood to be either a Master's thesis or a Ph.D. dissertation). Go to the library and check out some of the theses written by your predecessors in the department. If you are not the first graduate student supervised by your advisor, then see what sorts of theses have proven acceptable for him/her in the past. It also will begin to give you some ideas of the basic organization and structure of a thesis. If you are writing your first thesis ever, this is important. However, even if you already have done a thesis, reading other examples is going to give you useful ideas. You may form opinions about whether or not the authors ended up expressing themselves well or not. It is easier to avoid mistakes by first recognizing them in the work of others than it is to recognize them in your own work.

2. Start with a simple outline

For myself, I find that writing is easiest when I have an outline with major topics indicated and sub-topics already suggested. I don't necessarily have to follow the outline once I start to flesh it out. Far from it, in fact. It just helps to have something to go on besides a blank screen/sheet of paper. It is really useful to discuss that outline with your advisor before you get very far in the actual writing. This discussion with your advisor will probably force you to revise the outline, and it's easiest to do that before you have invested your time and effort in detailed writing.

It is possible to offer a suggested basic outline that you can use to put some structure into the thesis. Use the following as a point of departure; your university and department probably will have some guidelines about the required contents, the order of things, the acceptable margins on each page, the proper

paper to use, etc. Please follow their instructions to the letter; you're wasting your own time to try to stretch the rules, because they won't bend them for you ... guaranteed.

Abstract

Table of Contents

Figure Captions

Acknowledgments

I. Introduction

A. Discussion of what is to be done, why it matters, and where it fits

B. Literature review: what has been done in the past

C. Short (1) summary of contents of sections

II. Data

A. Source of data

B. Any problems with the data and how they are addressed

III. Data processing

A. Methods used

B. Limitations on the processing

IV. Theoretical background

V. Results

VI. Interpretation of results, including limitations on them

VII. Summary (short!) and conclusions, possible future work

References

Appendices

3. Use your research journal

If you followed my advice and kept a detailed journal of your work during the research phase of the thesis, then it should be simple to distill this into a thesis. Remember that not everything you did needs to be written up. You need not document the work you did confirming the obvious (see section VIII in the

text). Discuss with your advisor the desirability of including tangential topics; i.e., things you did along the way that are interesting but not necessarily pertinent to the main point of your work.

4. Longer is not necessarily better!

It is a persistent myth that a long thesis is more likely to be approved than a short one. There may be some faculty members who actually enjoy reading lengthy theses, but they would have to be a tiny minority. If you can say what you did effectively in fewer than 100 pages, including figures, references, and appendices, I have little doubt that your committee will be *pleased*, not offended. Moreover, there is a certain satisfaction when you recognize that your entire committee actually *read* your thesis, whereas there is a sort of regret when you can detect that only your advisor cared enough about the work to plow through 500 pages. There may be faculty who disagree with this philosophy, but I pity them and their students; in my view, short is good. Writing a thesis ought not to be an exercise in endurance. The idea is to express your ideas tersely, because the journals in which you will publish your scientific and engineering paper are going to emphasize terseness.

5. Express your ideas in your own way

There are many different opinions about scientific writing, and since this is my book, I'm going to emphasize my own biases here. Some folks think that scientific writing ought to be colorless, odorless, and tasteless; neutral, objective, and without a scrap of humanity showing. This apparently mirrors the myth that science is coldly objective. This little book is not the forum to go into this in detail, but I detest that image of science. I like to feel that when I read a scientific paper, it was written by a living, breathing, caring man or woman, not a machine. Hence, I believe that it is desirable for your writing to reflect your own stylistic choices. If you want to express yourself in some unique way, go ahead. The only pitfall in this is for your *style* to overwhelm your *content*. The way I am writing this book is far more idiosyncratic than would be acceptable in a scientific paper. You don't want your readers to be so enthralled with the *way* you are saying something that they lose sight of *what* you are saying. Scientific/engineering papers can be personalized without becoming an exercise in creative writing. It takes time to learn how to write well on technical subjects, but if your writing is interesting, it will enhance the number of readers of your work. After all, enhancing your readership has to be one the goals of writing up your results in the first

place. In the final analysis, if your advisor wants a paper that is colorless and dull, then you should write that way, but keep in mind that you can develop more interesting writing as you go.

6. Avoid certain pitfalls

There are several mistakes made by those writing their first thesis. I've already mentioned one of them: including expositions demonstrating the obvious. If you did something that confirmed that some obvious answer did not work, that might deserve a short mention, but avoid belaboring such points. There are other pitfalls.

i. Figure description

A well-conceived figure does not need to be described in the text. If you find yourself saying things like "Figure 21 shows a graph of chinkadera frequency as a function of time." then you are simply repeating the content of the figure caption. This serves no obvious need, since the reader can read the caption. Further, you may find yourself saying something like "As seen in Fig. 17a, a boundary passing through central Illinois separates the region of strong knutenary concentrations in northern Illinois from weak concentrations in southern Illinois." If your figure *shows* knutenary concentrations directly, then isn't this simply describing what the readers can see for themselves? Is there some point to be made by the figure? If so, make that point and cite the figure to illustrate the point, but you should not pad the text with descriptions of what the figure shows.

ii. Too many figures

When you find your thesis contains a lot of figure description and relatively little else, then this can be a symptom of having too many figures. This often springs from a desire to show everything you did. In general, it is not necessary to document everything; just enough to validate your interpretations. Opinions differ in this regard, but every figure ought to serve a purpose in the paper, not simply to document that you considered each item that each figure represents. Figures require captions, they take extra work to create, and (in my opinion) ought to be pared to the bare minimum to get the point of your paper across. If your advisor and/or committee members ask for more figures, fine. Go ahead and include what they asked for, but if they ask for them, it is a good sign that you have been diligent in

attempting to minimize the number of illustrations.

iii. Too many or too few references

Some students feel obligated to show how well-read they are, and so their papers read like a literature search. This attempt at being "scholarly" often goes too far, with so many references, there seems to be a bare minimum of original thought in the whole thesis. On the other hand, it is quite possible for there to be too few references, thus giving the impression that the author has been working in a vacuum in the literature. This is just as inappropriate, if not more so, than too many references. On the whole, I prefer too many to too few but it is best to try and strike some happy medium. As always, the advisor has the final say on this topic, of course.

iv. No focus

Many students seem to have trouble deciding on what is the main thrust of their thesis and sticking with it. In part, if you have kept a journal, you may be prone to this, because you will have a record of everything you did. The object in writing a good, terse thesis is to find the main point(s) and stick to it (or them), without a lot of wandering around. If you use the method of outlining and can stick to the basic outline once it's finalized by you and your advisor, it should be simple to stay with the point. If you start wandering away from your outline very far, you need to think through whether or not the wanderings are really relevant to your thesis. They may belong somewhere else, but keep them out of your thesis.

7. Redundancy

It's been said that you have to repeat something eight times before you can be reasonably sure your audience will remember it. Unfortunately, some people carry this too far, by repeating themselves in the Abstract, the Introduction, the text itself, and the Summary. If you are going to say over and over what it is you did and what you found, at least confine the lengthy expositions to the text proper and keep the summaries very short elsewhere! It gets tiresome to read the same things over and over again, so most readers will start skimming instead of reading with care about the second or third repetition. This may cause them to miss important points buried in the midst of all that redundancy.

8. Acknowledgments

A simple word to the wise, here. If you are uncertain about how much credit to give to someone who helped you out along the way, always err on the side of giving *more* credit than you are *certain* is due to that person. Think about it. If you helped someone and they never even acknowledged that help, how likely would you be to help them again? You can offend someone in this way and they might never say anything about it, but you might wonder why they are always too busy to help you out when you need it. It's possible to make an enemy for life in this way and not even know what you've done, and it is unwise to burn bridges this way. It doesn't cost you much to be grateful, and it can pay off in big ways later. Of course, you should want to be grateful to those who have helped you because it is the right thing to do, not because of the benefits you are going to reap. But if you only do it for the benefits, it still works.

Appendix B. Communication skills

I've already suggested that many science and engineering majors have neglected their communication skills during their education. If this is true for you, it can be a real problem for you after graduation, because a lot of what you will be doing as a scientist or as an engineer will involve communicating what you have done to others. In fact, your ability to accomplish that communication effectively can be crucial to your success on the job; promotions, allocation of resources, bonuses, etc. all can be strongly dependent on how well you communicate. Don't let this slip by in your enthusiasm for your technical subject matter.

1. Writing

For scientists, for better or for worse, their success is judged mostly by their publications. If you can't write so other people can follow what you have done, you will have a pretty rough time getting papers published in refereed journals. Writing your thesis and dissertation can be a good chance to learn what it takes to become an effective author, but developing the skills to write good scientific papers is not a matter of one or two tries. Be prepared to learn about writing skills for the rest of your career.

An excellent path to developing your writing skills is to read a lot of papers in your field. Often, contributing authors are asked to review papers within their domain of expertise. Take this job of refereeing seriously! As I've noted already, it is easier to see certain sorts of mistakes in someone else's paper than it is to see in yours, so if you give an author a hard time for doing something, be sure that you aren't guilty of the same sin. This is not the venue for a discussion of reviewing papers, but one benefit is that if you do it conscientiously, it almost certainly will make you a better author.

Clearly, writing takes practice, so you should plan on reporting on your work as often as appropriate. You can't learn a lot about writing just by *reading* about how to do it. You have do participate, and everything I've ever heard about good writing says that you will be doing a lot of revisions. Go ahead and plan for revisions, but don't try to write a perfect paper before you share it with someone else. This means you should pass the paper on to someone locally whose judgment you trust and who is willing to give it a careful, critical reading. And please develop a thick skin when it comes to criticism of your work! *A severe critic is your best friend* in learning how to write well; that critic will force you to

clarity of expression and will seek and find any weaknesses in your presentation. Do you really want to go to press with a weak presentation, or flaws in your reasoning, or misleading expressions of what you did, or poorly-executed figures? Better to find these and fix them in the review process than to have them pointed out to you after the paper has appeared for all in your field to see! Too many young writers (and even some experienced ones) shy away from criticism. Don't let this happen to you, and you will become an improved author every time.

Knowing when to stop the revision process before submitting your paper to review is going to take some experience. In general, at some point in the process, you will no longer be able to tell if the paper is really getting better with each revision. This may be so simply because you are thoroughly sick of the paper! This may be a signal that you need to submit your paper to formal review, and waiting for the reviews to come back is a good time to tackle another project, to get your mind off the paper. Then, when the reviews come back, you will be ready to finish the last round of revisions in response to the comments you have received.

Good papers that you read in the journals (Yes, there are good papers out there!) are not the result of a single round of writing by the author(s). Instead, they have been subjected to many revisions after many people have done careful reviews of the content and presentation that paper contains. Very few papers appear after having sailed through the review process without many changes, so get used to the idea. But it helps if you can at least create a good starting point with the first pass, so learning what works and what doesn't work in your technical writing is probably worth your putting in some effort.

2. Oral presentations

As with writing skills, it is likely that you are going to have a continuing real need for making effective oral presentations. If you have time in your course schedule and you have not ever taken a speech course, this might be a good time to find a spot for a speech course in your schedule. The main idea is to get some practice at speaking in "public." If you can get this by joining a local Toastmasters group (or some other way), then this will work as well. The main idea is to learn by doing, hopefully with some feedback from people who are knowledgeable and critical (and, yes, here's another place where a thick skin is helpful). I make no pretense of being a professional, but there are many pitfalls to avoid and tips I can offer to help you learn how to make oral presentations.

i. Learn to omit "filler" from your speaking

Many of us put "filler" in our speech unconsciously. When we are pausing to gather our thoughts for the next burst of speaking, we often use such fillers as "y'know," "like,", "uhhh," "well," and so forth. In order to hear what you do, have some of your discussion within a small group recorded, preferably when you are unaware of it, but even when you are aware of it the playback of your speaking still can surprise you. A simple device for avoiding this filler is simply to pause and concentrate on saying nothing during that pause. Perhaps we do this in our conversations to prevent others from leaping into our pauses and saying what they want to say. This habit is inappropriate in a presentation where we are not competing with others for talking time, and ends up being a distraction. Not every moment of your presentation needs to be filled with your voice!

ii. Maintaining eye contact with your audience

As you speak, it is useful to let your gaze roam about the room and make eye contact with individuals in the audience. This gives them the feeling that you are making the speech directly to them. If the group is small enough, you can do this with everyone in the audience at one time or another. In a large audience, this may not be possible and people in the back of a large room may not ever be able to see your eyes, but you still should look at individuals in the audience, if for no other reason than to keep yourself aware of talking to people, not the air. Don't talk only to the overhead projector or screen, please.

iii. Limit the amount of material covered

Although there are no hard and fast rules, you cannot make many points in a short time. I use as a good "rule of thumb" that I can only make about one point of substance for each five minutes of presentation time. Therefore, in a 15 min. talk, I try to make no more than three major points. Plan your talk accordingly and you should have no problem finishing your presentation in the allotted time.

iv. Limit the number of visual aids you use

Employing a visual aid, such as a figure, or a table, or a photograph takes time. Each such visual aid usually involves at least a brief explanation and usually requires that you take some action (unless you

have someone switching viewgraphs or slides or whatever for you at just the right times with no prompting on your part). I use the rule of thumb that I should have no more (and preferably, fewer) visual aids than there are minutes in my presentation. In a 15 min. talk, there should be no more than 15 visual aids. And if the visuals are multi-media (e.g., both slides and viewgraphs) then each *change* from one medium to another is allotted the same time as a visual aid. Thus, if I have 10 visual aids, and I make 2 transitions back and forth from slides to viewgraphs and back (so the talk goes from slides to viewgraphs to slides to viewgraphs to slides), that makes four transitions and I am just about at my limit for a 15 min. talk. If you have more visual aids than this, you will find yourself rushing through them so rapidly that most of the audience will get very little from any of them. A well-conceived visual aid (see section __) still must be visible for about a minute to be certain that the audience has grasped its contents

v. Do not read your visual aids

If you find yourself reading the contents of your visual aids to your audience, they will be able to read them silently much faster than you can read them aloud, so you will end up falling behind your audience. This is also a monumentally boring way to make a presentation. If I can read your viewgraphs, why do I need you to do that for me? A better strategy is to use your visual aids to prompt you to discuss items in a certain order and to avoid inadvertently leaving something out. I'll say more about this in section __.

vi. Make sure the content matches the presentation

Most of us have heard talks that seemed wonderful because the presenter was exciting, or dramatic, or funny, or whatever, and then when we had time to think about what was said, we discovered that the actual content of the talk was pretty shallow. And most of us have heard a speaker who had a lot of real substance to say but who was simply boring and clueless about how to make an effective talk. Your presentation should not overshadow what you are trying to say; rather, it should be focused on getting your points across. Being "cute" or making attempts at humor that are out of context (e.g., starting out with "A funny thing happened to me on the way to the Symposium ... " story) are good ways to alienate your audience. Technical presentations do not have to be boring, but neither should they be viewed as mere entertainment.

Keeping the knowledge level of your audience in mind is a common courtesy that few speakers seem to be able to do. If you are addressing a general audience, you shouldn't be solving nonlinear partial differential equations during your talk. If you are addressing a group of faculty members as part of a presentation of your research findings, you shouldn't include slides of your most recent family outing. This ought to be common sense, but it is disappointing how often speakers fail to take into account the type of audience.

viii. Put some variety into your speaking

Most of us have heard speakers who drone on in a monotone, with little or no sense of feeling in their presentation. If it is true that you care about your work in some way, it is quite acceptable and even desirable to have some of that excitement show through in your talk. Vary the level of your speaking volume; at times you might be close to shouting, and then revert suddenly to a near-whisper. If your speaking is always at the same volume level, this encourages people's attention to drift. The purpose of this is not simply adding drama to your talk ... that would be equivalent to putting entertainment ahead of content. The point is to get your audience's attention and keep it. If these "techniques" enable you to accomplish that, isn't it worth it?

ix. Listen to other speakers

As with writing, it is a good practice to attend as many talks as possible. This allows you to evaluate what speakers do well and what speakers might do that you definitely want to avoid. Learn how to evaluate the presentation separately from the content of the presentation. Your impression of a talk is often influenced by the presentation quality more than the actual content. Hence, this skill is something that will obviously be helpful, and you need to learn how to distinguish these two independent aspects of a talk.

x. Dealing with questions

Most technical presentations include a question and answer (Q&A) session or at least include opportunities for questions from the audience. These can be intimidating for new presenters. There are some important things to keep in mind.

a. Remember that you are likely to be the expert about the material you are presenting. If you did the work you claim you did, then almost certainly no one knows more about your work than you. There is no real reason to feel intimidated by the audience if you have done something worthwhile. If you feel uncertain about its worth, then perhaps you should re-consider making the presentation!

b. Some questions might well stump you. Do not feel obligated to guess an answer unless you admit in advance that you are only guessing. Ignorance often is forgivable in technical presentations and if you simply don't know an answer, a simple "I don't know." can be an appropriate response. If you are uncertain, then admit your uncertainty. If you made some sort of important mistake or omission, then admit it and be glad someone found your mistake before you went on to formal publication of flawed results. Honesty is definitely the best policy, as trying to "handwave" your way around a tough question only reduces your credibility.

c. Some audience members are on an ego trip and just want to show off how much they know. Remember that as long as you are the speaker, you are in control and should not willingly relinquish that control to someone in the audience. You might simply interrupt their interruption by asking, "Excuse me, do you have a question or are you just making a statement?"

d. At other times, a questioner may not accept a simple answer and wants to engage you in a long argument. This might be acceptable in some circumstances, but it often uses up the Q&A time that others might want to use. In such a case, it is quite acceptable to suggest that you will continue the discussion with him or her at the end of your allotted time, to allow others the chance to ask their questions.

e. You may get a question like "Did you consider the Gezockstihagen effect?" or "Did you

take into account the hyperphantic theorem?" If you did or did not, a simply yes or no is probably not going to satisfy the questioner. Be prepared to justify why you did not account for what is likely to be his or her pet topic. If it should turn out that you never even heard of such a thing, say so, and be prepared to defer a lecture on the subject by the questioner to after your talk.

f. At times, a question can be confusing. In such cases, it is valuable to get the questioner to clarify the question. You might ask "Are you asking me about this-and-that or such-and so?" Or you might respond with "If I understand your question, you are asking me to resolve the thermobaric flanxit issue in this case. Is that correct?" This not only ensures that you are indeed answering the question as asked, but also may buy you some time to gather your thoughts on the question.

3. Visual aids

I have already begun to mention some of the basic issues related to visual aids in the preceding section on oral presentations and even in writing. Figures and illustrations can be extremely valuable tools in getting your point across, but if you use them poorly (e.g., figure description in a paper, or using poorly -executed figures in a presentation), then they can be a *hindrance* to getting your point across successfully. The term "visual aid" is thereby a misnomer in such cases. What are the characteristics of a good figure?

i. A good figure makes one point

The object of a figure is to *show* something; this might include some theoretical results, characteristics of observed data, or some structure in calculations based on either theory or data. If a figure makes too many points, it usually becomes confusing to the point of not getting *any* of the points across. If numerical quantities are involved, the figure makes clear such aspects of the numbers as the order of magnitude, the scale, and the quantity (or quantities) being represented. Simple figures generally are more effective than complex figures. If you find yourself writing a long caption to describe the content of a figure, then you should consider simplifying that figure. It is not always true that long captions imply

a bad figure, but as a rule of thumb, if the caption is more than two or three lines of text, the figure may need simplification.

ii. A good figure is readily legible

Figures in papers usually are reduced from their original size. Figures used in a presentation may be viewed from considerable distances at the back of the presentation room. If the illustration is not legible at such normal distances, then the point will be that much harder to make. Journals likely will reject illegible figures and if you use them in a presentation, the audience's attention will be lost quickly. Visual aids in talks are notoriously bad at scientific conferences, often when tables of small numbers are jammed onto a single slide or viewgraph. An illegible or confusing figure is a waste of everyone's time, as it cannot possibly succeed in its mission to make some point.

iii. A good figure has visual impact without going overboard

Although they are most common, illustrations or visual aids with black lines or text on a white background often have minimal visual impact. If possible, white text or lines on a dark background usually work better in oral presentations. The written versions may be acceptable to journals as black on white, but you should always be aware of the value of illustrations that are visually attractive. Avoid being garish by using wild embellishments like fancy textures or psychedelic colors, as these tend to distract from the point being made. As was the case with your manner of speaking, the object is not mere entertainment and the point being made should not be overwhelmed by the presentation.

iv. A good figure's appearance is professional-looking

There is nothing inherently wrong with hand-done figures, but most of us lack the skills needed to make such figures look good. Right or wrong, the degree of confidence in the reader's or listener's eye is associated with the figure's professional appearance. Therefore, it generally is beneficial to have your illustrations done on a computer or by a draftsperson. There is no guarantee that good, well-executed figures will result from being done on a computer, though. It still takes care and skill to get a computer to give a professional-looking, effective visual aid. In my opinion, the skills of the professional draftsperson often are underrated, with the result that many professionals have bad figures that detract from their

intentions.