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TEACHING GRADUATE STUDENTS THE ART OF SCIENCE

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Abstract. Graduate students traditionally learn the trade of research by working under the supervision of an advisor, much as in the medieval practice of apprenticeship. In practice, however, this model generally falls short in teaching students the broad professional skills needed to be a well-rounded researcher. While a large majority of graduate students considers professional training to be of great relevance, most graduate programs focus exclusively on disciplinary training as opposed to skills such as written and oral communication, conflict resolution, leadership, performing literature searches, teamwork, ethics, and client-interaction. Over the past decade, we have developed and taught the graduate course *The Art of Science*, which addresses such topics; we summarize the topics covered in the course here. In order to coordinate development of professional training, the Center for Professional Education has been founded at the Colorado School of Mines. After giving an overview of the Center's program, we sketch the challenges and opportunities in offering professional education to graduate students. Offering professional education helps create better-prepared graduates. We owe it to our students to provide them with such preparation.

1. Introduction, the Need for Professional Training

Graduate school is aimed at preparing scientists and engineers to be the scientific professionals of the future. Those graduating, with either MSc or PhD degrees, pursue a career in a variety of areas of employment – in academia, industry, or government. Unsurprisingly, graduates with such advanced degrees ultimately attain high-level positions with their employers. Sometimes such positions are in the research field in which students have studied, but often the professional life sooner or later extends beyond the specialistic research in which the students are trained (Golde & Dore 2001). Even those pursuing a continuation of their research after graduation usually experience a change in their daily activities as they acquire progressively more responsibility such as in leadership of research groups. This suggests that graduate programs should prepare students to assume broad professional roles that go beyond those of the specialized individual researcher: universities aim to educate the professionals of the future and should educate students accordingly.

One might question the extent to which graduate students are, in practice, adequately prepared for carrying out their research while in graduate school. Where do students, for example, learn how to successfully choose a research topic, prepare a research plan, work effectively with an advisor, do a literature search and archive results, manage their time, and communicate effectively? One might hope that students learn such skills from their advisors and by being part of a research group, but how well are they in fact learning such skills in this way?

The mechanism for educating graduate students is essentially a medieval system wherein the pupil (the student) works with the master (the advisor) for several years. Once the master decides that the pupil has learned her new trade, the time has come to award the graduate degree. This is, of course, a caricature of graduate school, but it is one with a grain of truth. In practice, while students focus on research and disciplinary classes, some of them receive frequent and excellent coaching from advisors and team-members. Many graduate students, however, lack adequate mentoring in professional skills. This often leads to a loss of time in graduate school, needless frustration and discouragement, and an overly narrow preparation for a future career. As stated by Cassuto (2011):

> *"It amounts to this: Graduate school is professional school, but most PhD programs badly neglect graduate students' professional development. We spend years of their training ignoring that development, and then, only at the last moment when students are about to hit the job market, do we attend to their immediate professional needs."*

This view of graduate school might, in fact, be overly optimistic since it assumes that graduate students who are near the end of graduate training are actually taught professional skills. That might not even be the case.

The National Institutes of Health (NIH) carried out a study to determine the effectiveness of professional training given to graduate students and postdoctoral fellows supported by NIH (Mervis 2011, NIH 2011). The report identifies the need for adequate professional training. Berg (NIH 2011) writes in his role as director of the National Institute of General Medical Science:

> *"Ultimately, a healthy biomedical and behavioral research enterprise requires that government, academia, industry and other partners work together toward common goals that recognize the essentiality of high-quality mentoring and career guidance for the next generation of scientists. Our future, the future of discovery, and the utilization of such discovery for the benefit of humankind depend on it."*

This quote expresses that adequate mentoring and training of young researchers goes beyond the interest of individual researchers; the effectiveness of the whole research endeavor and its potential impact on society might depend on the degree to which young researchers are adequately prepared beyond the confines of their specific scientific field. Clearly there is a need to focus on the professional education of young researchers.

2. Are Graduate Students Being Adequately Trained?

Few systematic studies have been conducted that quantify to what extent the needs of graduate students for professional training are met. The American Institute of Physics carried out an "initial employment survey" among physics PhDs with first jobs in the private sector and who graduated in 2007 or 2008 (Ivie 2011). This survey showed that 98% of the graduates stated they work with their new employers on teams, 67% regularly speak in public, and 63% work with clients. This raises the question "Have these students been adequately trained in graduate school in the 'soft' areas such as team-work, oral communication, and client interaction?"

We asked a mix of MSc and PhD students in different stages of their graduate studies their views about the value of a range of professional skills including communication, conflict resolution, leadership, carrying out literature surveys, and teamwork. A large majority of the graduate students acknowledged the importance of broad professional training in general, e.g., written and oral communication, ethics, and leadership. Moreover, employers consider such skills to be essential to advancement of their young professionals and, by extension, to the success of their organization.

In our roles of advisor and dean of graduate studies, we discovered that the adaptation of students from different cultures to the work style in the

USA can take a considerable effort of the student and the advisor. Interestingly, NIH identifies the creation of a diverse workforce as one of five priority items; the NIH report (2011) states that *"diversity is an indispensable component of research training excellence, and it must be advanced across the entire research enterprise."* We currently are developing a 1-credit graduate course that helps students better understand cross-cultural issues that can arise in graduate school.

We also asked graduate students what they believe to be the most efficient method for delivering professional training. Surprisingly, students thought that interaction with advisors was the least effective way to provide such training. This is in striking contrast with the notion that the advisor is the person most important in helping their students grow to become young professionals. This suggests that those graduate students have not perceived the mentoring they experience to be of particular value to their professional growth. This does not mean, of course, that mentoring and advising is unimportant; rather, it reflects the fact that interactions with advisors currently often fall short of inspiring acquisition of general professional skills. Coaching academic faculty – training the trainers – might have fundamental value for increasing the effectiveness of academic advising and benefitting the professional growth of young researchers.

To advance their professional skills, students have the greatest preference for seminars or workshops, or to incorporate elements of professional training into regular courses. These two approaches are perceived to require their smallest investment of time, and therefore represent for them the most sensible options given the pressure they are under to finish a graduate degree in a limited amount of time. This preference for time-efficient options is, in practice, reinforced by some advisors who question the merit of broad stand-alone professional training. This attitude among academic advisors might be a result of their not having received formal professional education themselves.

Incorporating elements of professional education into disciplinary courses is not only time-efficient, it also has the merit of placing professional skills in the context of the discipline chosen by the student. One might question, however, how easy this option is to realize in practice because many disciplinary courses are already overloaded with content judged most pertinent to advancing students' research; moreover, teachers often have neither the interest nor the skills to broaden the scope of their disciplinary classes to include aspects of professional education.

In order to help students develop effective research habits and grow into professional researchers, one of us (RS) developed in 2002 the course *The Art of Science* at the Colorado School of Mines (CSM). In the next section we give an overview of topics covered in that course. Despite its relatively small size, CSM now offers six different graduate courses for professional training of graduate students. Furthermore, in order to coordinate these courses and to foster new initiatives for professional education of graduate students, CSM has founded a Center for Professional Education. We describe the scope of this center in more detail in Section 5.

3. The Art of Science

The course *The Art of Science* started at a modest scale, with about five students in the first year. Currently the class attracts about 60 students per year, which is about 25% of the graduate students that enter CSM each year. The class is taught to students from all departments. Several departments have made this graduate course mandatory for their students because they have found students to be more effective in their research after they have taken this class.

The growth in the enrollment in the course might be attributed to a combination of factors; one is that the class, which started out as a 3-credit course, was subsequently shortened to being a 1-credit one. This reduction in time-investment for the course was appreciated by students, and it also made advisors more receptive to their students 'sacrificing' some research time to take this class. This reinforces the conclusion of Section 3 that it is important that professional education for graduate students be offered in a manner that is time-efficient.

3.1. COURSE CONTENT

The curriculum of the class, including its homework exercises, can be accessed online[1]. The course currently covers the the following topics, that range from the philosophical to the rather nuts-and-bolts applied:

- What is science?
- Making choices
- The advisor and thesis committee
- Questions drive research
- Giving direction to your work
- Turning challenges into opportunities
- Ethics of research
- Using the scientific literature
- Communication
- Publishing a paper
- Time management
- Writing proposals

[1] `http://inside.mines.edu/~rsnieder/Art_of_Science_curriculum.pdf`

– The scientific career
– Applying for a job

Each of these topics is covered in much more detail in the textbook (Snieder & Larner 2009) (see Fig. 1) that grew out of this class; here we give just an overview of each of the topics in the course.

What is science?

Given the breadth and depth of the topic of the philosophy of science, one could readily teach a separate full course on the scientific method. For students who are almost always pressed for time, however, it is useful to restrict the class to material that has immediate and practical implications for their research. Science is based on logic; a statement that is inconsistent with logic might well be interesting or beautiful, but it cannot be considered part of science. Science nevertheless often makes its largest advances based on such non-logical, ill-defined abilities as creativity, inspiration, insight, and intuition, and the seemingly unscientific activity of play. And, then there's the fortuitous element – serendipidity. Successful scientists appreciate the great paradox that science is an activity that, while a description of nature dependent on logic, often moves forward through pathways that are not logical at all! Although students are generally aware of this paradox in at least a vague and unarticulated way, it helps students be more creative in their research when the existence of this paradox is highlighted. Introducing students to the intuitive part of science and its value gives them license to venture into tapping into their creative, perhaps illogical, talents (Schwartz 2008). It is the combination of the logic and the intuitive creative talents that makes science a true art, hence the course title *The Art of Science*.

Making choices

Students face many decisions in their choice of graduate program, advisor, research topic, and future career path. The need to make choices, of course, continues after graduate school as well; whenever confronted with having to select what is hoped will be a good decision, it is essential to be well informed. One part of being informed is to get the information from the right people. When choosing an advisor, for example, it is not only important to talk with potential advisors, it also pays off to talk with their students, especially former students, as well. Making the right choice of research topic has far-reaching implications for success in graduate school and satisfaction in later career and life. A suitable research topic must be innovative and doable, it must match the research facilities and the time that are available, and it should also offer the promise of instilling a passion in those doing the research. We teach students the concept of the "S-curve of development" wherein a research field goes from initiation stage through

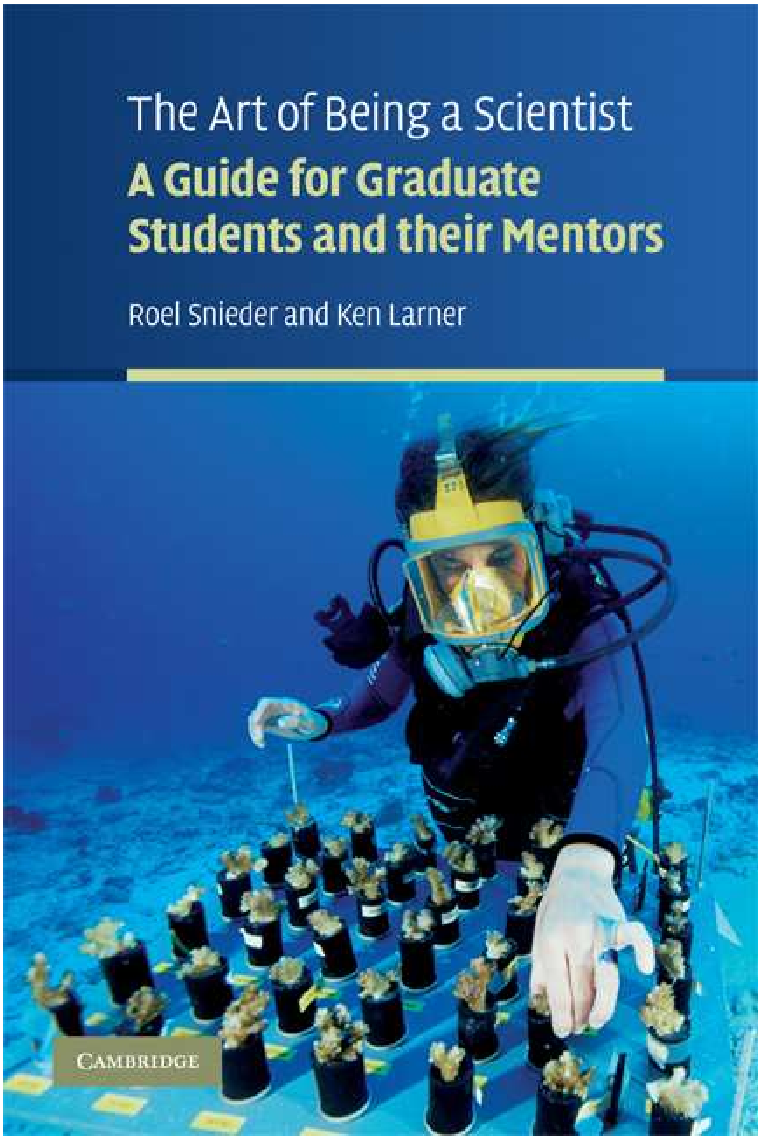

Figure 1. Cover of the book *The Art of Being a Scientist.*

exponential growth to maturation. Having (1) an awareness of differences in challenges and opportunities that these three stages present, (2) a recognition of the stage a particular line of research is currently in or might soon enough be in , and (3) an understanding of which stage of research best matches the student's technical, creative, and emotional strengths can assist in making the right choice of research topic.

The advisor and thesis committee

The advisor is a central person in the career of a graduate student. Not only does the advisor need to sign off on specific stages of graduate study, of more consequence is the essential role that the advisor ideally plays in mentoring the graduate student towards scientific independence. The perfect advisor is a creative and respected researcher, a dedicated mentor (Vesilind 2001), she challenges the student but provides support when needed, has ample time, and has financial resources and infrastructure for the research. Clearly that perfect advisor is hard to find. The situation is, in fact, even more complicated. Different students need different types of advisors. The insecure over-achiever needs, for example, a different style of supervision than does an overconfident self-starter. As students change over time – and they should change as they grow through the graduate program – the style of advising that works best for them will also change. Given that the 'perfect advisor' is an illusion, a student's task is to try to make an optimal choice, one that likely involves some degree of compromise, rather than a perfect choice. In *The Art of Science*, we aim to help students by making them aware of the elements that could be part of the choice and by giving them ideas for going through the process of choosing an advisor. Students, moreover, need to learn how to make effective use of their advisor (Kearns & Gardiner 2011). Related to this is their use of the thesis committee. Many graduate students see this committee just as a machine to provide signatures, but with the right outlook (of both the student and the committee), the committee can play a valuable role as sounding board for crucial choices in a student's research and education.

Questions drive research

An interesting exercise is to pose graduate students the following assignment. *Please complete the following sentence in not more than 20 words: "The main question I want to address in my research is ..."* It might be surprising to find that many students have difficulty in completing this sentence. That difficulty arises because they lack clarity on the very research question they aim to address. But how can one expect to find an answer if it is not clear what the question is? It is fundamental that students understand the significance of asking questions in research. Some of these questions are major overlying ones, some are more specific with a focus on a particular practical problem. The 'right' questions are ones that almost automatically lead to actions in research. The best start at asking the 'right' question comes from asking lots of them – both 'good' ones and 'stupid' ones, simple ones and bold ones. It can take courage and imagination to ask bold questions. The question "What would be the consequences if the speed of light were the same for all observers?" posed by Einstein is at first sight nonsensical, yet it changed our world-view because it led to the theory of special relativity. In the course, we offer students ideas for generating research questions, ideas that range from writing them down as they arise during the day (or night), to talking with others (students don't often enough recognize one another as a resource), and to free association. The questions thus generated form a natural basis for making a work-plan for the research project.

Giving direction to your work

A quote from Lewis Carroll states that *"If you don't know where you are going, any road will take you there."* The purpose of setting *goals* is to clearly define where you are heading and what you want to achieve. Without articulating goals, random events or other people are likely to define the way in which our life and career unfold. Students should learn that if they don't define where they are headed, somebody or something else will (indeed, also should researchers and people in general). But setting goals is not all; one also needs to be aware of *process*. What is the value of reaching a goal in graduate studies when the process of getting there is not attractive? Clearly the process of doing research must have its rewards as well. This offers a second perspective on giving direction to our work: being process-oriented. Ultimately a third perspective can come to the fore: what is the *meaning* of our work? What does our work mean to us, to the scientific community, to other people, and to the world? Whose life is touched or improved by my work? The key in setting direction is to reconcile goals, process, and meaning. This is not easy, and many of us never get to that point, but being aware of these complementary aspects of our work is an indispensable first step.

Turning challenges into opportunities

Research is challenging. One challenge that is bound to arise – often – is being stuck. There are, roughly speaking, two reasons for being stuck. The first is having insufficient clarity on the research question that one aims to address or on the path that one intends to take to address those questions. This problem can be paralyzing and needs to be fixed as soon as possible using the techniques described in the section on posing questions. The second reason for being stuck is that something is 'wrong' in the sense that one's understanding is incomplete. While frustrating, this source can actually be highly positive because it can be a precursor to gaining new insights (Kuhn 1962). Not a small aspect of his approach to research, Lord Kelvin emphasized *"When you are face-to-face with a difficulty, you are up against a discovery."* Students need to learn what activities help them in getting unstuck. For some of us, for example, running is an activity that is conducive for getting new insights when these are needed. By developing an awareness of activities that are helpful in getting unstuck, students can become more effective in getting out of seeming impasses they invariably will encounter. In the course, we also discuss the role that play and serendipity have in opening new avenues of thought and for research.

Ethics of research

The ethics of research is often seen in the restricted sense of "responsible conduct in research." That view of research ethics focuses on issues such as honesty, avoiding plagiarism, and appropriate sharing of authorship – important issues that students need be aware of. In practice one often cannot repeat and verify experiments done by others nor can one easily chase down all possible antecedents to reported research. Students therefore must recognize the extent to which the advancement of science is founded on trust. Moreover, students need to be made aware that honesty and preservation of one's reputation is especially challenged when economic interest lies at the heart of a scientific or engineering endeavor. Yet there is more to research ethics than the need for honesty. It is through dissent that science moves forward beyond current understanding; science cannot advance when everyone is in agreement and is satisfied with current viewpoints. In his wonderful book "Science and Human Values," Bronowski (1956) emphasizes that science is underpinned by honesty and advanced by dissent. Yet, as illustrated in the parody of Oxman et al. (2004), not every scientist has developed the skills to disagree respectfully and express dissent in a constructive way.

Apart from these issues of how research is carried out, it is essential to the growth of a student into a mature and contributing researcher to gain the insight that research is not value-free. In this highly technological age, science has the potential to affect society and the lives of others either negatively or positively; often a given scientific advance can have both positive and negative ramifications. A heightened awareness of such potential consequences can be a valuable guide toward choices in research whose impact on society and its environment is positive.

Using the scientific literature

Research projects should begin with a solid literature search. Students sometimes skip or minimize this step and, as a result, either duplicate work of others or make their work unnecessarily difficult by failing to take advantage of the insights of others. Over the years, the scientific literature has grown so much that it is difficult to keep pace with. Students need to learn how to use the powerful electronic tools available for searching the literature effectively. Furthermore, it is important to develop a modern data base of references: such a database makes it possible to retrieve papers easily and to generate a bibliography at the end of papers or a thesis with the touch of a few buttons. In the course, we make our students aware of free database programs such as Zotero[2], Mendeley[3], and Jabref[4]. As a homework exercise, students must choose a system for managing bibliographic information and show that they have started using the program of their choice. We have found that without the reinforcement of such an exercise, although the class tends to be interesting to students, it might not lead to helpful behavioral change. Nevertheless, not all approaches for keeping up with the literature ought to rely solely on electronic tools and information technology. A journal club, for example, with stimulating discussions on research among colleagues, can be a great aid to maintaining awareness of current research.

Communication

Career advancement for a scientist, whether working in academia, industry, or government, can be governed largely by the young researcher's ability to communicate, both orally and in writing. We emphasize that, *effective* communication is difficult. For both oral and written communication of research, perhaps the most difficult skill to learn is to place oneself in the shoes of the reader or listerner. This skill is essential for setting the level and tone of the communication needed to reach the audience and peak its interest. In oral presentations, one must be aware of the short attention span of most audiences (Medina 2008), indeed the relatively short time available to convey research and results that could well have taken a year or more for the presenter to have generated and understood. Young researchers need to resist the temptation of over-feeding the audience with material that, despite the availability of modern projection resources, is poorly readable (Benka 2008, Payne & Larner 2008). An effective way we've found for teaching students the do's and don'ts of oral presentation is to show them a spoof presentation in which the teacher does everything wrong, and to discuss what is amiss in this presentation afterwards. Because few of us can give an outstanding presentation while improvising, students need to expect that preparing for an effective oral presentation is hard work that requires extensive rehearsals, the audiences for the rehearsals consisting of both colleagues who familiar with the work and those who are not. Moreover, the friendliest of rehearsal audiences has members who care enough about the success of the final product to offer in-depth critiques of both the content and details of presentation style. Similarly, any well-written manuscript usually has gone through many revisions that often rely on the input from caring colleagues who act as severe proofreaders, in essence the

[2] `http://www.zotero.org/`
[3] `http://www.mendeley.com/`
[4] `http://jabref.sourceforge.net/`

first line of reviewers. Also, before embarking on the writing, both students and advisors can save much time by decoupling the content of a paper from its style. This can be done effectively by first developing an outline that is so detailed that the content and flow of the paper are virtually predetermined. Once this is done, the 'only' thing that needs to be done is to formulate this content into words[5]. Our next advice is to 'blast away' in putting words on paper, with little concern for either the audience or word choice. Then comes the essential next step: revise, revise, revise – progressively choosing wording and writing style aimed at increasing clarity for author's intended reader.

Publishing a paper

Obvious as it is that publishing of a paper starts with the choice of a journal, junior graduate students are often unaware of the differences in scope and quality of journals. We discuss the impact, so to speak, of the *impact factor* as well as other considerations to take into account when choosing a journal. Examples include the readership of the journal, the speed of publication, the cost of publication, and the journal's reputation. As mentioned in the previous section on communication, when planning a paper for publication it is essential to know the audience for whom a paper has been written. Students should understand the mechanics of the review process and be aware of opportunities to steer that process, for example by suggesting names of reviewers and associate editor who might be best suited to handle the manuscript, people who are especially knowledgeable about the subject of the paper and who can be counted on to treat the work fairly. Also, knowing how best to respond to reviews, particularly those that might seem at first unduly critical, can be an art in itself. Students need to learn to take the comments of reviewers seriously, without being carried away by indignation when a review at first sight feels unduly critical. The comments of reviewers more often than not are a great help in improving a manuscript; they can point out segments of a paper that are in need of further clarification not only for them but for the intended readership. Students, however, also need to know that they, as authors, are allowed to deviate from the suggestions of reviewers if they can convey their reasons for disagreement. Always, the author should respond to specific concerns raised by reviewers in a cover letter to the editor, stating point-by-point how they have addressed the concerns, including those about which the author was not in agreement with the reviewer and therefore were not incorporated in the revised version of a manuscript.

[5]Most students have learned this in high school, but seem to have forgotten this by the time they are in graduate school. Many advisors have forgotten this as well, with the result that they unnecessarily grind their way through repeated lengthy drafts to

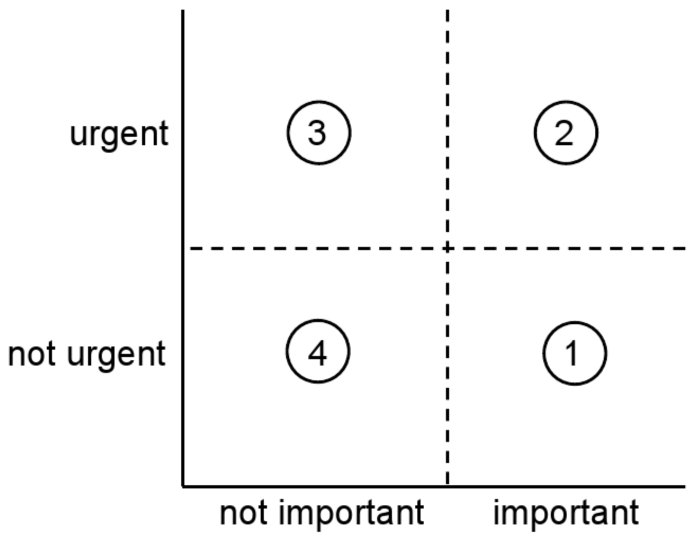

Figure 2. A categorization of activities. (adapted from Covey 1990)

Time management

Many of us feel as though there is not enough time for all that we have to do. This is, however, an illusion because, for everyone, a day always has 24 hours, and a week seven days. Nothing will change these basic facts. The feeling of not having enough time results from our trying to do too many things in a given amount of time. The word 'time-management' therefore is a misnomer; the difficulty actually boils down to one of 'activity-management'. This is not just a semantic distinction; students need to learn that is essential to make choices about which activities to spend their time on, and which not. It is illuminating for students to consider the diagram in Fig. 2, adapted from the book of Covey (1990). Roughly speaking, all of our activities are either important or unimportant, and they are either urgent not urgent. This is, of course, an oversimplification because both importance and urgency vary on a sliding scale, but for the moment we make this simple distinction. Given the criteria of urgency and importance, each of our activities fits into one of the four quadrants of Fig. 2. Many of us make the mistake of confusing urgency with importance with the result that the important activities tend to fall by the wayside to urgent, but actually less important, ones. As a homework exercise, students monitor their activities for a week and insert into the diagram of Fig. 2 each activity, with the time spent on it. Students also insert into the diagram activities that

discover that they disagree with the main structure and content of the manuscript.

they would have liked to do, but did not find time for. After that, they analyze the way in which they have spent their time, and make a plan for improvement, if needed. We discuss in class that saying "no" is essential in activity management, and discuss why this often is so difficult. Learning how to gracefully say "no" is an important skill, and we give suggestions for ways in which to offer alternatives to requests, or directives, from superiors. (When we say "yes" to a request, we are often saying "no" to something else that we might otherwise do.) We also point out that, useful as they often are, electronic tools such as cellphones, email, and the internet, they can also be a severe distraction. We caution students to be the master of these tools, rather than their slave.

Writing proposals

Regardless of whether a scientists or engineer works in academia, industry, or government, writing proposals is an integral part of her job because one must, in general, explain why time and resources need to be expended on research. Every proposal starts with the choice of to whom the proposal is to be submitted, and one needs to be informed in order to make this choice wisely. When writing a proposal it is essential to stick to the guidelines given by the funding agency. Such guidelines include tangible issues such as the length of the proposal, as well as less tangible ones such as the specific points that must be addressed in the proposal. One should also be aware of the way in which proposals are handled. Many junior researchers do not realize that members of a review panel often are faced with having to read more than 1,000 pages of proposals. These panel members obviously don't have the time to do this; hence a proposal, starting with the abstract, must make a favorable first impression. As scientists we often feel the urge to be complete in our proposals, and explain all facts and details that we feel are important to us. This, however, is not what reviewers, panel members, and program managers are looking for. They seek a concise description of the state of research in a field, the research question that one aims to address in order to advance the research field, the research methodology used, the competency and facilities of the research team, and the proposed time-line and deliverables.

The scientific career

In order to make the right choices for one's career (choices again), the key, as before, is to be informed. We discuss the structure of the academic career and its opportunities and hurdles, such as the tenure process. Students should know that the nature of the tenure process varies significantly among universities and that the degree of fairness of the tenure process varies much as well. A useful and practical guide for best practices in tenure evaluation is available online[6]. The choice of employment in academia versus industry or government is a major one for graduates. Because their training takes place at universities, many students in science have apparent familiarity with the university work environment, but limited understanding of what it means to work in industry or government. In the class we aim to give them insight into differences and similarities that might be expected. As a homework exercise, students interview four researchers, preferably from different types of employers, with the goal of gaining greater insight into the choices available to them. We also discuss gender issues. Despite many efforts, there still exists a gender disparity in engineering and in the higher ranks of scientists. We point out several mechanisms that have brought about gender bias. (Did you find the use of the word "she" instead of "he" in this chapter strange, or even disturbing?) Balancing professional and personal life is a challenge in the scientific career; we find that students are keen to discuss this topic. For female students the topic of combining motherhood and family responsibilities with a successful career is of particular interest.

Applying for a job

The application for a job begins with identifying several potential employment opportunities. As with all choices, one first must gather facts. For this, students should rely not only on recruiters and human resource managers, but also hear the opinion of employees and former employees. An appropriate and well-constructed letter and curriculum vitae are essential, and job seekers need to keep in mind that the relevant information must be made easily accessible for overloaded search-committee members and managers. During an interview, the person seeking employment should be pro-active. This can make the interview more useful as a fact-finding tool; moreover, a pro-active attitude usually is viewed favorably by people conducting interviews. Also, because promotions and significant salary increases are infrequent events once an individual is employed, it is important to negotiate before accepting a job offer. Although the class includes no time to cover negotiation in depth, we do point out the different styles of negotiation: win-win, win-lose, and (hopefully never) lose-lose. The job application process should aim for making an optimal match between employer and employee, which obviously calls for seeking a win-win strategy. Some industrial employers are unduly restrictive in the rights granted to their employees, for example by insisting on long-term non-compete agreements after employees leave the organization to work elsewhere. In order to avoid unpleasant surprises when starting at a new job, the job appli-

[6] `http://www.acenet.edu/bookstore/pdf/tenure-evaluation.pdf`

cant should be clear about all conditions of appointment *before* accepting a position (Larner 2002).

3.2. TEACHING *THE ART OF SCIENCE*

Since 2002, we have offered *The Art of Science* as a graduate course at CSM, and have also given this class as a short-course at numerous universities that include Stanford University, Tohoku University (Sendai, Japan), Delft University of Technology (Delft, Netherlands), Australian National University (Canberra, Australia), and King Abdullah University of Science and Technology (Jeddah, Saudi Arabia, Fig. 3). We have also presented *The Art of Science* as a short-course for the research laboratories of ExxonMobil, Saudi-Aramco, and Shell.

The class has consistently received positive reviews from students. One student commented that

> "The Art of Science *was an eye opener for me. It made me think of my career and my life differently. It gave me energy and ideas to restart and continue when I am stuck."*

When teaching physics courses, we never had a student say that our course changed their view of career and life! Having a far-reaching impact on students is an important aspect of offering a class such as *The Art of Science*. An anonymous student at an international university wrote in an evaluation that

> *"I am glad I found this course early in my academic career. If only my university had required faculty members to come to your class! Thank you for putting all the things together which otherwise probably would have taken me years and many unfortunate incidents to figure out."*

This comment expresses that taking a class such as *The Art of Science* can save graduate students much time. This feedback recurs often in evaluations. Students often express regret that they had not taken the class earlier because that might have saved them time by being more efficient and by avoiding time-consuming mistakes. Taking a 1-credit class in the practice of science does take some time out off a busy schedule, but the increased efficiency and effectiveness in doing research, and in communicating that research, can readily make up for the time investment. The student comment above also indicates the wish that faculty members would attend course. This points to a need for training faculty to teach the skills needed for being an effective scientist. Although most faculty members are dedicated to advance research together with their students, much could be gained by training academic faculty in mentoring.

In numerous lectures about teaching *The Art of Science*, we typically have received a response from faculty along the lines "it would be great

Figure 3. Discussion during a break in the short-course *The Art of Science* at King Abdullah University of Science and Technology (KAUST). (Courtesy Marie-Laure Boulot, KAUST Winter Enrichment Program)

to offer a course like this in our department." The reality, though, is that developing and offering such a class takes time of faculty who are already struggling with their workload. We aim to reduce the time needed to start teaching a course such as the *Art of Science* by making our curriculum and homework exercises available, as examples, in the book (Snieder & Larner 2009) and through the internet[7] . Following are several options for offering this type of graduate education.

- The most straightforward scenario is to offer the class as either a departmental or interdepartmental course. This option requires a dedicated faculty member who is able and willing to champion such a course. For this scenario to work, the department or institution must recognize the value of such an educational initiative.
- One can broaden disciplinary courses to include elements of professional training. We have found that this option actually is most preferred by students who have not taken the 1-credit course. It does, however, require dedication of teachers to make time available to include professional training in their disciplinary courses; not every teacher has the skills or the time available in her course to offer such traininig.

[7] `http://inside.mines.edu/~rsnieder/Art_of_Science_curriculum.pdf`

- It is possible to share the teaching load by offering the class in the form of a reading group or seminar that is led, in turn, by different faculty members. This reduces the workload for individual faculty members and it might help create a greater involvement from faculty members. This scenario also makes it possible to draw upon the strengths of different faculty members.

Offering such training in any of these forms requires time of students and teachers. We do believe, however, that because of the improved the efficiency that students gain, it helps them ultimately to save time. Perhaps more important, it helps students to become more creative and more efficient researchers.

4. The Center for Professional Education

Currently the graduate program of the Colorado School of Mines includes the following courses for professional development:

1. The Art of Science
2. Introduction to Research Ethics
3. College Teaching
4. Advanced Science Communication
5. Academic Publishing
6. Professional Oral Communication

Given the small size of the school, the breadth of this course-offering speaks to the dedication of the school to professional training of graduate students. The class "Introduction to Research Ethics" was developed in response to the requirement of the National Science Foundation (NSF) that undergraduate students, graduate students, and postdoctoral fellows, receive training in research ethics.

In order to coordinate and facilitate professional education we have founded the Center for Professional Education[8] at CSM. Initially, the Center serves primarily graduate students, but over time might extend its activities to undergraduate education as well. The Center coordinates educational activities that include courses for broad professional development of students, seminars and workshops for students and faculty, and a speaker series. The Center brings together faculty dedicated to educating graduate students who are well prepared for the workforce, and acts as a nucleus for writing proposals to support initiatives for professional education, including new methods of delivery. Activities of the Center are directed not only toward helping graduate students, but also toward providing assistance and

[8] `http://cpe.mines.edu/`

support to faculty so they might improve their advising skills. The Center can serve a number of purposes.

1. Develop more rounded graduates. Graduates compete with highly qualified graduates from other institutions for positions in academia, industry, and government. As such, graduates strive to find ways to distinguish themselves from the competition. While technical competence remains the most valued aspect of graduates, students can distinguish themselves through development of professional skills.

2. Advertise educational activities. The presence of the Center makes it possible to advertise our activities for professional education. This helps, for example, in recruiting top-level graduate students and in soliciting external support through foundations for graduate education and research contracts. Advertising the possibility of gaining professional skills could be particularly helpful in attracting top-level international students.

3. Support new proposals. Pressure has been increasing for generating proposals to the NSF, NIH, and other funding agencies that require broader education for graduate students. The presence of an active Center with a broad offering of courses strengthens proposals that must include elements of professional education.

4. Conduct research on education in professional development. The Center will engage in education research in professional development by initiating and coordinating such a research effort, and by helping to solicit funding for such research activities.

5. Ease the task of advising students. Much of the time spent advising students tends to be devoted to disciplinary discussions that are at the core of the research experience. Training graduate students in professional development helps them be more effective in their research, in interacting with their advisor, in improving their interaction with their advisor, and in developing essential oral and written communication skills. Such training makes the task of advising easier, and hence reduces the workload of advisors.

6. Initiate new activities and bring the relevant faculty together. The Center is a nucleus to bring together faculty with a passion for professional development and to coordinate their efforts toward the creation of new initiatives and improvements of existing efforts. The current course offering does not cover all areas in professional development that are relevant for graduate students. By organizing seminars, and workshops, and by initiating the development of new courses, the Center serves to expand the scope of professional education.

5. Conclusion, Challenges and Advantages of Professional Graduate Training

In offering professional education to graduate students, we have encountered a number of challenges. First, teaching aimed at encouraging change in the behavior of students to make them more effective scientists, does not necessarily lead to such behavioral change. Most teachers know the phenomenon that students who have learned certain material in class are unable to use that material a semester later. This also holds for professional training. In order for material to stick with students, it must be repeated and reinforced regularly. For professional training it takes the dedication of the academic advisor, or refreshing the experience in other courses, to provide such reinforcement. Second, it takes an effort to get graduate students and their advisors to buy into professional education because the time needed for such education at the outset appears to them to decrease the time available for research. Our impression is that professional education makes students more efficient in their studies and research, even taking into account the time needed for the professional training. In the absence of hard data to substantiate this claim, however, it can be difficult to convince others of the value in devoting time for such professional training. This is aggravated by the fact that not all scientists appreciate the relevance of teaching and learning topics beyond disciplinary skills in their narrowest sense. Third, it does take resources, in particular time, to offer a broad professional education. Realistically, the required time and other resources are made available only when the institution acknowledges the importance of professional education.

Professional graduate training offers a number of advantages for students. First, being better prepared for scientific work can help minimize unnecessary frustration and loss of time both in graduate school and beyond. Second, it can help increase both the quality and quantity of the scientific work done in graduate school. Third, students learn skills to become better collaborators and to work more effectively with advisors. Fourth, such training should help students communicate their research more effectively. Fifth, broad professional training helps students be better prepared for the job market, and, sixth, it helps students to be better scientists.

Advantages also accrue to academic departments and their faculty members who offer professional training. Such training helps students to be more effective in their work, thus reducing the workload of advisors. For example, we discovered in our research group (the Center for Wave Phenomena[9]) that offering students a class on academic publishing in combination with tutoring to improve their writing skills saved a large amount of time for ad-

[9] `http://cwp.mines.edu/`

visors assisting students to write their thesis and publications. Moreover, offering an attractive program of professional education can help attract better students. As is generally appreciated, the quality of students is essential for the well-being of an academic research group; raising the level of incoming students elevates the scientific creativity and productivity of the whole group. Last the requirement of funding agencies to offer professional training is growing rapidly. The recent report of NIH (2011) points in this direction. Both NIH and NSF now require training in research ethics. The 'broader impact' criterion of the National Science Foundation is becoming increasingly important, and large programs such as the Integrative Graduate Education and Research Traineeship (IGERT) of NSF require professional education. Having an institutional program for professional education in place not only helps to offer such training, it obviates the need for individual faculty members to develop such training, and it increases the chances of success in funding of proposals.

More than any other reasons for offering professional education to graduate students, we owe it to our students to give them the best preparation possible to be the professionals of the future. Graduate students ought not be viewed as cheap labor to help us in our research; rather, the primary purpose of a graduate program is to educate young researchers who carry the torch of science forward and assure the continuity of the scientific endeavor in the best possible way. We should prepare them for this work as well as we can.

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[10] `http://www.phd-survey.org/`

[11] `https://www.mercy.edu/faculty/Georgas/inbs640/files/WhatMakesaLeader.pdf`

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[12] `http://publications.nigms.nih.gov/trainingstrategicplan/Strategic_Training_Plan.pdf`
[13] `http://inside.mines.edu/~rsnieder/Art_of_Science.html`