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HOW TO 'SURVIVE' AFTER GRADUATING IN MATERIALS SCIENCE II: BASIC ADVICE

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ABSTRACT

This article summarizes some basic advice for prospective and recent graduates in Materials Science (and related disciplines) on how to apply the skills and knowledge they have acquired in graduate school to finding a job and developing their career in the '*real world*' of science. Since the job market for Science and Engineering graduates has become increasingly competitive over the last two decades, we argue that the new generation of researchers should learn to act as their own agents/managers so as to '*sell*' their expertise to prospective employers. Our three basic pieces of advice can be summarized as follows: (i) *know yourself* analyze your strengths and weaknesses objectively as well as your likes/dislikes and career aims and make your choices accordingly; (ii) always *plan ahead*: make flexible short term, medium term and long term plans as this dynamic mode will help you seize opportunities as they present themselves; (iii) *learn to play from the other side*: since anything that matters in the world of science is peer reviewed, learn to place yourself in the mindset of those who are going to evaluate you so as to anticipate their moves. This is the second article of a series, following the first in which we described how we set up the graduate course on "Survival Skills for Scientists" at INRS.

INTRODUCTION

Earning a doctorate, or Ph.D. degree, and, with that done, ending formal course requirements does not mean the end of formal learning; it merely means that the learning process has now become a matter for self-directed individual enterprise.

For the young scientist, besides the actual science itself, and apart from reminiscences of successful scientists (where some useful anecdotes may be found), there is little information to be found in terms of practical advice to help in making the many choices that fall under the headings of the strategy, tactics and planning which can arise in making one's way in science. This article is the second of a series in the Journal of Materials Education, a series which is aimed at helping to fill this gap.

This article (following the first article on how we developed the course on 'Survival Skills for Scientists' at INRS[1]) is intended for anyone who wants to improve their standing in the large community of research scientists whose success and career advancement depend directly on the results that they publish in peer-reviewed scientific journals[2]. Since this does not include all those who are termed scientists in the broadest definition of the word, it is worthwhile to make this aspect a little more precise.

There are those who decide at the bachelor level that, while they want to be involved with science, they do not want to enter the competitive arena of peer-reviewed research, and would rather teach, or become patent examiners or serve in some other capacity such as science writing. However, while these careers involve science, these people are not practicing scientists as such and so this series is not aimed at them (although it is entirely possible that some of our advice is useful to them as well). For all those who continue in graduate research, whose thesis is to be validated in the public arena of science, that work should be at least published in a peer-reviewed journal, so peer review is important for them. However if they are not planning to continue in the peer-reviewed publication arena, they can afford to leave most of this aspect in the hands of their thesis advisor. This includes those who, similarly to some after the bachelor's degree, may choose to leave the competition in peer-reviewed science after acquiring a postgraduate degree, for fields such as teaching, science writing, patent work or other occupations where they do not need to develop further their skills for scientific research. Then there are those who choose to become research associates. (By "research associates" here we mean those who work under supervision but do not aspire to direct research, thus acting more as high-level technologists rather than scientists). While research associates will certainly be well advised to work hard at developing their research skills, they do not have to concern themselves directly with how their work is presented in the science peer-reviewed forums. Finally there are also the careers as research scientists which while they require all the research scientist skills including directing the science of others, are evaluated essentially outside the peer-reviewed publication paradigm, which means in practice scientists who are mainly in industry or in government research laboratories. The path of success for these scientists does not rest mostly in the open peer-reviewed literature, but within the judgment of their superiors in their laboratories or research teams. (However it should be noted that if one of these scientists ever wants to turn from these areas to the arena of peer-reviewed science it will be important to have maintained a respectable level of publications in indexed journals.)

With this clear understanding that not all scientists need to acquire the expertise of handling communications in the peer-reviewed literature, we now return to our main preoccupation, those for whom success as evidenced by peer-reviewed publication is a vital measure of success. Within this community we directly address the young, or early career scientists on their way up the ladder; this includes not only current graduate students and post-doctoral fellows but also young scientists further along on their career paths. However there is also much that the 'older' scientists (meaning those further ahead in their careers) can gain from the advice contained in this series of articles in helping to understand the professional preoccupations of younger colleagues.

Before we begin we briefly discuss what our advice is *not* about. What our advice is *not* about is finding and following a simple and magic recipe to be a better scientist as such. While we discuss some work habits and practices which can help, in essence we put aside the level of raw talent and motivation (which must however be realistically evaluated by each scientist on their own) since these lie far beyond the world of recipes and good advice. You either have those qualities or you don't; there is no amount of reading material or advice that can compensate for lack of real talent or motivation[3]. (One question which you should ask about the science itself is, “Are you still having fun?” If the answer is less and less satisfactory as time goes by, then you need to see what should be changed.) Now that we have clarified what you will *not* find in this series of articles, we turn to the subject at hand, namely what we will be discussing.

This article (together with the others in the series) discusses the many practical issues which a young scientist ought to know, things which are not, in and of themselves, scientific at all. They are the techniques, the tactics and the strategies for advancing your career so as to rise upward in your scientific community, sometimes referred to as ‘soft professional skills’. For a classical musician this would be equivalent to help and advice in making the decisions ranging from whether to become a member of an orchestra or a concert performer or a teacher, to what competitions to enter, to how to evaluate what general style of music to concentrate on, etc., but nothing on the actual practicing, playing or interpretation, i.e., nothing on the actual music itself, which is the realm of musical talent and genius.

To sum this up, our aim here is to help you to help yourselves to make your way in science, leaving the purely scientific part to you. Without this knowledge and its application, your progress in the world of science will be essentially left to chance. Any would-be entertainer or author acquires the services of an agent, a manager or editor to help in managing to help planning career moves. After hearing so many scientists say something to the effect of, ‘I assumed someone would look after me’, we decided to write this series of articles which aims at helping you become your own agent.

Your position is very similar to that of a young artist in the Renaissance. In that setting it was not enough to develop skills and vision, it was equally necessary to plan to get into the good graces of a patron to support you in the pursuit of your art.

Most scientists (and nearly all those beginning in science) unfortunately only attend to these matters when faced with an imminent and pressing deadline of some sort. When that is the case, only a minimum of planning can be done and that only at the last minute. (Last-minute planning is barely better than no planning at all!) You can do far better if you take the trouble to tend to your career periodically at least on something like a weekly or monthly basis, on average. This brings us naturally to the first basic piece of advice, stated below.

THE ZEROTH LAW OF SCIENTIFIC SURVIVAL: PAY ATTENTION TO YOUR CAREER!

We call the first and basic piece of advice the “zeroth law” of scientific survival. (This is, by analogy with the zeroth law of thermodynamics, the one that underlies the others.) The zeroth law of scientific survival to attain success in science is, simply, *pay attention to your scientific career and do so regularly and frequently*. In other terms, *you* need to take care of number one – because nobody else will! This is pretty obvious as a general concept, but before we go further we should try to set out what a scientist such as you might mean by “success in science”. To understand this aspect it is convenient to look at the field of science in which you hope to work in terms of those who are already in it.

THE WORLD OF SCIENTISTS: APPRENTICES, ARTISANS, ENTREPRENEURS, WIZARDS

Much of a particular field of science can be grasped by looking at the various roles played by the people who actually do the science. This done, one can characterize one’s ambition and (later) actual achievement according to what role you play or would like to play and in what group you play it. While it may be tempting to organize a sort of hierarchy in team play with labels such as alpha, beta and so on, it is more useful to de-emphasize what ordering there may be and to concentrate rather on how scientists actually operate in science.

Of course, besides these practitioners of competitive peer-reviewed science, there are also a few who could be called ‘philosophers in science’, whose work is driven by more or less pure intellectual curiosity. However when one looks more closely one usually finds that (in our times at least) these people earned their way to that status by brilliant competitive performance over many years, after which they may well be able to run a modest pure science enterprise founded on their reputation. To reach this status you would be well advised to pay attention to what is being offered here; after you have attained that eminence you can relax and enjoy yourself and manage your career less intensively. (There are also dedicated teachers, but while they may be called ‘scientists’ and cannot be called ‘unscientific’, other scientists would rarely term them ‘scientists’ in the usual sense of someone actively involved in cutting-edge science and creating new knowledge. Their evaluation of these teachers and popularizers is essentially in the hands of their students or readers, and not at all in the peer-reviewed scientific literature).

Of the practicing peer-reviewed scientists, one can roughly distinguish four main kinds of scientists, which we are here labeling as *apprentices*, *artisans*, *entrepreneurs*, and *wizards*.

The *apprentices* are the graduate students and the post doctoral fellows (“postdocs”), who have had their basic training and are beginning to find their place and level in their science. In any experimental aspect of science there is a great deal of craft required to design and construct new experimental arrangements and apparatus which is done by *artisans* and made to work by some other *artisans* (often requiring a different set of talents). These aspects are generally organized by *entrepreneurs*, who have usually emerged from the *artisan* groups (usually by competitive evolution), and who also are responsible for overall strategy, for procuring funding, for recruiting and the like. There are also those scientists who do not fall into this way of organizing things which we here label as *wizards*. These *wizards* include both theorists and those individual experimental scientists who have very few other artisans working with them. *Wizards* are in effect mini-entrepreneurs who have as their responsibility students, perhaps a technician or two and a post-doc or two, but with groups so small that no real group structure issues are involved. (While this was a common model in “The Good Old Days”, the complexity of modern science means that fairly significant numbers of people are usually required, so now only a few “wizards” are astute and talented enough to make the modest team viable in a well-crafted niche.)

In any field there are the alphas, the “rock stars”, the ones who are in the top branches of the tree of reputation. The role of an alpha is to lead, and manage, a research group (note the deliberate distinction between ‘leading’ and ‘managing’). Perhaps they are alphas just because of their sheer individual talent and drive, in which case they are also what we here call *wizards*.

Other alphas acquire that status because of a *combination* of talent, motivation and *managerial ability* (this last is especially the case if large groups or teams are required for advanced projects), in which case they are most successful *entrepreneurs*. (Note that managerial ability requires some talent, but much of it consists of skills that can be learned and do not require scientific talent as such.)

The alphas are the “movers and shakers” and implicitly determine amongst themselves most of the major activities in the field. As one might expect, there are rarely more than one or two alpha scientists in any team or group. (In an analogy with classical music, one may liken entrepreneurs to conductors, artisans to musicians in the orchestra and wizards to concert soloists who may also conduct on occasion).

Let us return to the entrepreneurs, since when one begins to perceive the limits of one’s talent and suspect that one is not a natural wizard, it is tempting to seek to rise further by developing and employing entrepreneurial skills and by becoming an entrepreneur. When an entrepreneur forms a group or begins to run a group, one of the usual goals is for the group to grow, and one should ask whether it is necessary always to grow. Of course there are always external limits to growth, but what a clear-headed entrepreneur has in mind is to grow up to the minimum viable size to maintain an adequate 'cruising speed' (in other fields this would be called 'growth to a sustainable level'). A difficulty is that this perceived 'sustainable' level may grow merely with the entrepreneur's enjoyment of the growth process. A career trap of the opposite kind for successful entrepreneurs is that they may find themselves eventually doing very little actual science beyond choosing who and what to support. The advantage of being an entrepreneur is that you have considerable power to choose, so you can if you like choose to stop being a group leader. However, if you choose to step away from the seat of power, to do more of your own science, your range of choice will certainly diminish, and that may be hard to accept. But at least the entrepreneur has a choice.

Of course, although the overall direction of the team work is in the hands of the entrepreneurs, the bulk of the hands on work is actually directed and done by what we here term the *artisans* and these artisans are far more numerous than the entrepreneurs or the wizards, so you are most likely to become an artisan. The *artisans* usually know the science extremely well, but they do not have alpha status, either because of a relative lack of demonstrated flair and brilliance (in effect beta scientists), or because, while they may have the talent, they really prefer to stay closer to the science and not to do the arduous but necessary organizational and fund-raising spadework to keep a group going. (The best artisans may in fact be quiet *wizards*.) The artisans may thus be divided roughly into three groups. There are those who are top-drawer scientists who have chosen not to compete with alphas (but may be in effect quiet wizards, and control much of their own destiny on a modest scale). There are scientists who have become valued specialists and are comfortable in that role, and are really enjoying their science. Finally, there are those who have chosen not to give more to science than can be done in normal working hours, what one might call craft workers, usually specialists in some essential aspect. They are good, perhaps even excellent at what they do, but have given up being concerned with the 'big picture'.

As a first step in looking at the particular ecology of the domain in which the young scientist will be working, it is a useful exercise to look at some of the familiar figures in the domain of interest and to classify them as wizards, as artisans or as entrepreneurs, with a view to using them as models to emulate or avoid.

The apprentice scientists would normally hope to enter the ranks of junior artisans and learn to become aware of how the science is being done, both in the home group and elsewhere. While apprenticing as artisans, junior scientists should also evaluate their progress and adjust their goals in view of their actual performance, but many (probably most) do not. (While Socrates as a true philosopher said that "The unexamined life is not worth living", most people seem to fear examination of their lives, as if, for them at least, it is the examined life that might not be worth living.) Those who do not analyze their progress simply carry on whatever they have been doing. If they do not reach the goals which they originally aimed for, they simply let these early ambitions fade and accommodate themselves implicitly to reality. This is an easy course and has the merit of minimizing distress and the corresponding defect of giving a performance well below what could have been. Our work is not intended for those who would accept this policy of drift but rather for those who want to do the best that they can with what they have and can become and thus to gain autonomy and freedom of choice to practice their science as they wish to. We aim to provide some of the tools to enable them to be able to make their own choices rather than relying on those of one entrepreneur or another.

Let us recall what a scientist is and what scientists do. There are two kinds of scientific research, curiosity-driven or pure science and goal-driven or applied science.

The main goal of curiosity-driven or pure science is to investigate the laws of nature, and to provide and report new knowledge and insight into the physical, chemical and biological processes of systems which exist already or which are created for investigation. In this perspective, curiosity-driven scientists are those who burn with the desire to unravel some particular mysteries of nature that lie close at hand in their area of expertise. The other aspects of the job are essentially the means to achieve this end.

In contrast to this, much (if not most) of science research is goal-driven or mission-oriented or applied to some end, where the funding comes from a desire to make advances in areas of interest to society as a whole, or to profit by specific economic opportunities. Once it becomes clear that a particular aspect is not going to contribute to the end as defined by the "client" (i.e. the funding agency or the company or some other program), the research effort is turned elsewhere. It may well be easier to get support for mission-oriented research, but one must be prepared to be required to stop working on something before you are ready to give up, simply because the support for the project is exhausted. (In curiosity-driven research the usual reason for stopping is because of complete success or because one runs out of things to try; both are fairly rare occurrences).

The distinction between the two can become blurred when aspects of mission-oriented research are so large and enduring that they remain desirable for an anomalously long time and have become in effect objects of curiosity in themselves.

Whether in curiosity-driven research or mission-oriented research, real scientists who are performing well enjoy their work very deeply. Any "real scientist", if offered the same salary by an intelligent philanthropist, but without the necessity of having to do anything specific for this money, would usually choose to carry on in the same way as at present. A real scientist is, in fact, essentially addicted to the science and does not view it as a job or chore but rather as a 'game'. It is well known that a good question to ask a post-doc is, "Are you having fun?" The same applies to "real scientists" who should be asking this quite often in science, with the follow-up, "If not, why not?"

If you are a true scientist, your enthusiasm will clearly emerge when you give a talk, or when you write a scientific article or even a grant proposal. Your peers will look up to you with respect, sometimes with awe, and consider you as a source of inspiration (except the fraction who are jealous or envious). You will get very excited (a science "rush" in fact) when you or your students acquire new results and now understand something that nobody has ever understood before. This excitement and enthusiasm are the true rewards of a scientist, and they make up, or at least should make up, for most of the drawbacks, pitfalls and "sacrifices" that come with the job. It is important to keep this in mind to face the rough times that undoubtedly lie ahead. A scientific career is tough and full of unknowns, especially at the beginning. However, very few people love their jobs and enjoy them as much as scientists do, and this is to be considered as an enormous fringe benefit.

Even though personal remuneration is usually not the primary motivation to the real scientist, money is most certainly important, though not in the usual sense (for non-scientists) of personal remuneration for the scientist in person. To the real scientist "money" really means funding in the form of grants and the like, which is necessary to pursue the desired research. Without sufficient funding and resources it is very hard and challenging (though not altogether impossible) to do good science, so obtaining the funding is a necessary (but never completely adequate) means for an end. (This said, unfortunately some people in research do come to consider money, in the sense of funding, as an end in itself[4].) Research entrepreneurs deal directly with this problem, while many artisans and even some research wizards rely on the entrepreneurs to do it for them.

Modern open science is distinguished by a fundamental reliance, for the maintenance and building of the scientists' reputations, on publications in the open literature and patents. By this is meant publications which are refereed by generally anonymous scientific peers, hence the term "peer-reviewed literature" or often just "literature". In literature-dominated science this process tends to establish a fairly tight positive feedback cycle — more good publications — more funding — more research success — more good publications and so on. Success in science is usually predicated on operating this cycle successfully. As well as doing the required science, it is clear that handling and optimizing your input to the literature is extremely important.

Still on the subject of money, let us deal in passing with your own personal money. If your basic goal is to become rich and famous, not in terms of your research accounts but in terms of your own bank account, we strongly suggest that you pick another career that will let you attain those goals and fulfill your aspirations in a simpler and faster way (For example you could try to become a techno-industrial wizard like the co-founders of Google). Since there are already more than enough *prima donnas* and empire-builders in science who are really driving for the best science, there is no need for more who are mistakenly counting on science to make them rich. It is true that the odd scientist does win a share of the Nobel Prize, and may thus become famous (for a scientist, that is)[5] and moderately rich. In addition, a very small proportion of the scientists who have founded companies did manage to do rather well and earn themselves considerable sums. However these people were nearly always (allowing that there may be exceptions of which we have no knowledge) entrepreneur scientists who, on encountering an opportunity, then proved to have enough in the way of managerial and entrepreneurial skills (not to mention luck) to win through to profitability. Pursuing a scientific career in the hopes of finding such an opportunity is a poor bet and not worth considering as a realistic option.

Not only are you unlikely to become rich through science, and likely to work long hours, but also, a scientific career will not have the compensating advantage of many an office job, which is that of being in a safe and settled routine. In an active research program with several components it is extremely rare to have two days that look alike. If you are upset without a steady routine, we advise you not try to be a successful scientist. If successful in your research, you may be required to travel frequently to attend meetings and conferences, and to give seminars on your work. While this will be rewarding for you and good for your scientific reputation, it will not make your family terribly happy (if you managed to find the time to start a family in the first place), unless you systematically bring your family with you, of course (which is rarely practical, unfortunately). Dedicated scientists feel comfortable under these conditions, because they literally love their job and have loads of fun while working. But it is not for everyone or for their families.

Despite what has just been said, there are exceptions in the other sense, in that there are scientists who work in a regular schedule like office employees. These are some of the artisans who have settled in the science niches in which a routine "nine-to-five" scientist without some considerable "fire in the belly" can operate. The point is that these positions are just that, niches, and not way-stations on a path to greater success in science. In taking such a position in a way that is more or less permanent, you should realize that you would be essentially joining the ranks of the many middle and lower level artisan scientists in the world who are essentially well-educated technicians in a stable niche position. They usually co-author the papers (naturally in subordinate positions); they may lead small technical projects, and they have accepted that they will work on projects decided by others. By way of compensation they can use the extra energy which did not seem to be productive in pure science, to pursue other interests outside science. This is a perfectly valid role for those that choose it, but it should be a conscious choice, as in “I really like science, but I like my family and my other activities just as much or more, and so I willingly choose this useful, enjoyable but secondary role as my compromise.” What you should not do in such a position is to try vainly to be a top (or at least excellent) scientist (an entrepreneur or wizard scientist, so to speak) and then to settle resentfully into such a secondary role (perhaps blaming the machinations of others), working in a “nine-to-five” work-to-rule manner as an implicit protest at the loss of an early dream. (Naturally, if your choice of the nine-to-five mode has been made, if you have already dropped out of the race to reach entrepreneur or wizard status and into a essentially non-competitive niche of being an very good artisan scientist, then this series of articles is only of sociological interest for you, perhaps as an aid to understanding what the “upwardly mobile” people around you are doing).

Having dealt with the general nature of the roles that scientists can play in science, we now move on to mention some of the things that a scientist usually needs to do as well the actual science itself.

SURVIVAL SKILLS FOR SCIENTISTS

Many young scientists, like many young people generally, are undecided. They drift along hoping that something good will turn up, like a swimmer in a large river hoping a useful boat will float to within their grasp. They avoid planning, partly because they are frightened of the future (and perhaps because they are secretly hoping that they will suddenly stumble on a gold mine). They do not yet know themselves well enough to be able to estimate how they would work in a given environment (they do not yet *know themselves*), nor do they know the workings of the world of science well enough to estimate how a particular type of employment would work for them (they do not yet *know the tradecraft*). This series of articles furnishes tools to do both. For a more complete reading, we refer you to the modest number of books that are currently available[6,7,8,9,10,11,12]. (Far more advice can be found on buying a car or a house or starting a business!)

The basic operational aspects of the “zeroth law” with which we began, namely *pay attention to your scientific career and do so frequently*, can be organized on the basis of *five laws*. All the laws are equally important, and they are as follows, in their natural order of application in the context we have just outlined: (the first law) “*Know thyself*”, (the second law) “*Know your tradecraft*”, (the third law) “*Know thy neighbor*”, (the fourth law) “*Plan Ahead*”, (the fifth law) “*Play Chess*”. What do we mean by these five laws?

THE FIRST LAW OF SCIENTIFIC SURVIVAL: “KNOW THYSELF.”

“Know thyself.” Before you apply the other “laws” you should apply the first. Just as a good agent studies his client, you should study your client — yourself— not only as you might know yourself in life, but as a player in the “game of science”. Pay attention to yourself (being as objective as you can) and to your strengths and weaknesses, and figure out how to improve your competence. Do not try to be the perfect scientist, but try to be the best scientist *you* can be. (This advice is for *you*, not those others.)

Even more basic questions are “*Why* do *you* want to become a scientist? *What* will *you* be able to contribute?” If you have not yet asked yourself these simple questions, it is high time to do it. It does not make much sense to try to become a scientist if you do not know what your deep objectives are.

It is also very important to make a significant effort to “Know thyself” [13] so that your goals are realistic and so that their attainment will indeed satisfy you when you achieve them. The important questions to be asked include, for example, what should be your career goals as a scientist? In the terms introduced above, assuming that you are entering the apprentice class of scientists, are you seeking to become a wizard or even an entrepreneur? If so, are you aware of the commitment that will take? Are you prepared to make that commitment? Or do you see yourself as an artisan? Or, if things turn out well, as a wizard? This evaluation of your commitment should not simply include what you would like to achieve as a scientist, but evaluation of your commitment to what is needed to advance in your career so as to have the *means* to do what you want. As stated above, science can rarely be performed adequately without suitable resources, and access to resources tends to be very competitive. Asking yourself these questions openly, critically and realistically at each stage of your career (preferably well before the next stage is to begin) is crucial. It may save you from a lot of trouble and frustration, later on. Of course you should not forget to ask yourself this set of basic questions from time to time later in your development as a scientist (say every few months at least), and not just at the moment when you begin to think of a career change. In order to "Know thyself" on a continuous basis you must update, not just your *resumé*, but your self-evaluation and your goals.

Many young people begin working on a topic because it feels exciting, but when it becomes difficult (as it will), they can be quite shocked, almost like falling out of love. (As T.S. Eliot has written in *Murder in the Cathedral*, "Ambition comes when early force is spent.") Thinking of the early love affair with science that we all had, this really means thinking about whether you want to marry your lover and stay together for life for better or for worse, or whether to cut your losses. If you do not come up with what you think is a reasonable answer, it is wiser *not* to pursue a scientific career before too much time and energy are wasted. (However, you should by all means at least finish your degree if you are still a student, and then look for a different way to use your talents. A science degree can be applied in many different forms of employment, not just in scientific research).

THE SECOND LAW OF SCIENTIFIC SURVIVAL: "KNOW THY TRADECRAFT."

"Know thy tradecraft." In many spy novels (in particular in those of John Le Carré) the useful word "tradecraft" means the technique of organizing the mail-drops, the packaging and sending of information and so on. In the phrase "published science research" is included not only the actual science you do but much more. This "much more" is what we are here terming "tradecraft". At the basic level, "tradecraft" means, among other things, the craft of writing papers that people want to read and refer to, the art of constructing seminars that are fun to hear and to give, the technique of learning how to perform in an interview and much, much more. At this level you are targeting other scientists at large rather than any scientist in particular. At the more advanced levels to follow, "tradecraft" will be developed and deepened to include the art of initiating contacts with others to advance your professional ambition and your science and ability to tailor your tactics to the occasion and to someone or to several people. Another aspect is how to craft the various documents you will need to succeed such as applications for positions, fellowships and the like, perhaps research proposals and their components. Of course to do this effectively you must learn how to read the people to whom your efforts will be directed. (See below under "Play chess.")

THE THIRD LAW OF SCIENTIFIC SURVIVAL: "KNOW THY NEIGHBOR."

"Know thy neighbor." Pay attention to the people with whom you will be interacting. Work diligently at putting yourself in their shoes so that you can do a better job of tailoring your impact on them, i.e. on the scientific community you belong to. These will include co-workers, supervisors, the audience of your seminars and oral presentations in general. If you have ambitions to become an entrepreneur it is essential to cultivate your ability to become sensitized to what other people are thinking and feeling. Just asking people what they think tends to draw them out, and the cultivation of the habit of listening carefully is invaluable.

THE FOURTH LAW OF SCIENTIFIC SURVIVAL: "PLAN AHEAD."

"Plan ahead." While this is generally a good idea for most things in life, one might well ask, "What does this phrase mean here?" With these first three basic "laws" in mind, and with a commitment to an ongoing effort to develop yourself along the lines of these three basic laws, you are ready for the next fundamental piece of advice for a successful scientific career. This basic concept is simple enough to say but takes a disciplined effort to put into practice. It simply is: *plan ahead to do the best you can in your scientific career*[14]. The theme of this article is how to apply this basic piece of advice in various aspects of your scientific activity. Like much good advice it seems trivial, but, as is so often the case, it is rarely carried through in practice. *Do not plan just your work in science; plan your career in science.* If you want to be efficient about it you should keep a planning diary. (Reading it over every few months will help alert you to the characteristic planning errors you will make.)

You should think of your work as a turbulent river down which you are being swept. There are dangerous rapids with fast currents and dangerous obstacles which you can use to make better progress at some risk, as well as safe stagnant pools where no progress is made, not to mention disastrous falls and the like. Clearly you can do much better if, instead of letting yourself be carried passively by the current, you plan ahead as much as is feasible and set yourself up to profit by unforeseen opportunities and to take action before being overwhelmed by disaster. The same concepts apply to your career in science. Those who plan ahead and are ready to profit by opportunity are far more likely to be able to do the science that they most enjoy and have more control over how it is done than those who do not. Those who *let* things happen to them will wind up becoming servants of those who *make* things happen. This does not mean that to do the science you would like to do you should try to become a local despot of science like a military officer or the coach of an American football team (although some few may find their success that way). Between the solitary scientist (with perhaps a graduate student or two, and perhaps a post-doc), and the 'czar of all the Russias', there are many successful modes of operation and collaboration which are more democratic, informal and fun than either of these extremes. The point is to be able to find the mode you like and be successful in that mode and happy with your life and your science.

Early career scientists should think very carefully about short-term plans, as well as medium-term and long-term plans. It is important to think as far ahead as ten years in the future. Do not worry about whether your plans or dreams will come true. Most young people are content with taking their lives one day at a time, without any attempt at long-term planning. This is also true for young scientists, who are often ill at ease (feeling almost guilty) about planning their careers (or even about planning what they will do next year). Unfortunately, they do not realize the extent of the threat this carelessness poses to their futures. Scientific research is a world of opportunities and of competition to take advantage of them. In this sense, careful planning can be extremely helpful, especially in terms of having an alert and prepared mind. As is so often the case, if you allow this aspect of careful planning to appear too obvious, it will engender distrust in some who know you. (Tudor:- My father was fond of quoting a 19th century comment referring to young officers who played billiards too well in the regimental mess, "To play billiards well is the mark of a gentleman, to play billiards too well is the mark of a misspent youth.") One could say that, "To plan your science well is the mark of an astute scientist, to appear to be going to extremes in this will brand you as a conniver, schemer or 'operator'."

To succeed, you must be ready to seize the opportunities as they present themselves. In the end, however, while good advice can be golden, we emphasize that it is really experience — your own and that of the people around you — that is a scientist's best teacher, provided of course that the experience itself is not fatal to one's career. (This is a deliberate echo of Nietzsche "That which does not kill us makes us strong.") The risk and trouble is, however, much, much less if you learn as much as you can from other people's experience first, rather than your own. The advice we are trying to provide is an example of an aid from which you can learn without having to suffer excessive risk yourself.

Since the guide is not perfect, merely our opinion, it should itself be read critically, just as you would read a scientific paper. Our advice does not contain all the solutions, but is rather designed to get you to think seriously and objectively about your future. Thinking in this way about the problems that lie ahead is the first and necessary step to figure out ways to consider these problems in advance and thus to have your plans ready *before* the problems arrive.

Incidentally, if you think you have all the answers already, or that planning ahead is a waste of time, you are probably more in need of guidance than others. Blind arrogance is a very dangerous attitude for someone who wants to become a scientist. Rather, while maintaining a healthy mix of skepticism and self-confidence in one's own ability, the successful scientist must be open to new data, to novelty and to surprises, to take the best course of action when trying to unravel the mysteries of nature.

To repeat, our central message is to promote awareness of what to expect in pursuing a scientific career, to stimulate you to ask yourself many questions, and to try to make plans in advance. If you do all this, we will consider our effort to be a great success.

THE FIFTH LAW OF SUCCESS IN SCIENCE: "PLAY CHESS AND LOOK AT THE GAME FROM THE OTHER SIDE."

"Play chess" is a phrase meant to encapsulate a concept from many games, in that good game players not only look at the position from their point of view but should also practice looking at the position as it looks to other player(s). By practicing doing this you can improve many things in how you present things to other people. In other words when you present anything, be it an oral presentation, a manuscript for publication, a proposal for funding, etc., you should try before the presentation to do your best to see what you are offering from the general point of view of those to whom it is offered or submitted. (This is not the same as "know thy neighbor", because the written work is usually addressed to people you do not know. Hence your work is aimed at a reader of a certain kind, rather than at specific people.) Without actually "knowing your neighbor" directly you are gaining insight into the point of view of "the generic other", the likely reader of your publication, the audience for your talk, the judge of your research proposal.

This theme will recur in our discussion in future articles when discussing submissions for publications, for fellowships, for funding and the like. Like the advice to "Plan ahead", it seems obvious, but it is remarkably difficult to do in practice. For all such submissions one should, of course, find some actual person to whom you can present the submission (but it should be someone who is not too close to what you are doing). However these "victims" will have much less work to do (and will be more willing to do more or to do again) if you can do much of the external scrutiny beforehand by yourself.

MATCH YOUR GOALS TO YOUR CHARACTER AND TALENTS.

Now that we have discussed how to look at science and how to look at your own qualities ("Know thyself"), it is time to put these two aspects together. Which of your character traits are likely to lead to success in science? Sufficient scientific talent is obviously a necessary condition to be successful as a scientist. While raw talent can be refined, it cannot be created. Other things being equal, one would expect success in accomplishing science to be positively correlated with this native raw ability. While one can consciously try to explore various ways to give this ability free rein, the basic ability itself is probably not something that can be consciously learned or developed. To find one's basic level in any field it is vital to have a just opinion of one's basic ability in that field. This can be very difficult to do, and, while it is not something we will discuss here, the beginning scientist should make a serious attempt to do this.

One tragedy that is common, but not always consciously recognized, occurs when the talent level required for success in a particular field actually exceeds the raw talent of the scientist. In effect the scientist has, so to speak, "run out of talent". The only real cure is to move into a different field requiring less of whatever talent it is, or even out of research. However, before doing this, provided the will is there, one should realize that any level of talent can be made much more effective by making best use of some particular traits and also by developing and strengthening others. In effect what we are saying is, "Don't stay in a game which is over your head, but do not quit until you have given it your best shot with all your resources." It is at this point that science-related careers may become viable solutions.

In the meantime, it is obvious that, given your particular character traits, there are certainly some fields or modes of working that are more suited to your character than others. A rational way to handle this is to decide what "research style" is likely to appeal to you, since that is probably the best way to channel your energies.

Contrary to most people's beliefs, it is not the raw talent for science that is *the* most important trait that ultimately determines a researcher's success. Much success in science (particularly in experimental science) depends on other behavior which, unlike basic raw ability, can be learned, improved and developed. Another analogy is sailboat racing. There is a basic ability or "touch" in being able to coax a little more speed out of a sailboat, but there are also many things than can be consciously learned, anticipating tactical problems, boat preparation, weather prediction, many aspects of sail trim etc. There are books which describe what to learn about everything except the sailing "touch". Our aim is tell you about everything except the "touch" in your field of science. The "touch" you must supply yourself.

To drive this point home, we now make it in reverse. There are many admittedly clever and ingenious research scientists who are more talented than most others but who are not as successful as you would expect them to be, judging purely on their talent. Certain character traits, such as drive, patience, and the ability to lead a team, are extremely useful; they are perhaps more important, in the long run, than raw talent. The people who seem very talented but are not as successful as they 'should be' are those who have not realized that talent alone is not enough.

WHAT KINDS OF TEAMS OPERATE IN YOUR SCIENCE?

One of the important aspects of the science domain in which you wish to work is the nature of the normal method of functioning in that area. The basic concept here is the size of the typical team in the field, and this can be estimated by looking at the number of authors on a typical excellent paper, as well as at the author affiliations.

Something like five authors or less indicates a typical small team with, normally, a team leader or dominant scientist (we are calling such people entrepreneurs; in the fields of materials science, physics, chemistry and engineering they are not necessarily the first author, but often the last), a student (or two or three, one of whom is likely to be first author), a post-doc (or two), perhaps an “intermediate” artisan scientist, and sometimes another collaborating artisan scientist, likely from another institution.

As one goes up to something like ten or more authors, the work is likely to be the result of a coalescence of smaller teams working on different aspects of the research (Psychologists tell us that as a group reaches ten or twelve it tends to break into subgroups; in any case the entrepreneurs at this level are likely to organize sub-groups for efficiency.)

Yet another mode is that of a scientist (perhaps with two or three local collaborators) who carries on extended collaborations with other groups as a roving specialist collaborator sub group. (This is a mode which one of the authors (Tudor Johnston) has employed for years with considerable success.)

You should talk to people in the groups pertinent to your science and find out how the research is carried out and compare it with what goes on wherever you happen to be. Then you can make a rational plan, which may include moving your domain of research somewhat, to be able to operate in an environment more suited to your preferences (e.g. larger versus smaller teams).

In answering questions of this type, you should try to assess (as objectively as possible) your abilities to work with others and then see to what extent you are willing to compromise. You should not necessarily view this kind of compromise as something negative or demeaning. It is very likely that you will have to live with this kind of choice for most, if not all, of your career. At the beginning one often has little choice but to be one of two types of player, either a sort of laboratory technician/ student or a relatively low-level team player artisan; the possibilities for real choice will emerge only somewhat later. Nonetheless you should have clear in your own mind which way you want to go well before the first opportunity arises to make your own choice.

Once you have analyzed the field of interest to you, the next step is to think carefully about what style of scientist and science would make you happiest.

WHAT SORT OF PLAYER ARE YOU GOING TO BE IN THE GAME OF SCIENCE?

Let us begin with an obvious analogy, namely team sports and the role of the individuals on the team. In team sports, each player has a specific role. Take football (soccer) for example. There are eleven players on the field: typically one goalkeeper, four defenders, four midfielders, and two attackers. In a scientific career the situation is very similar, except that we maintain that there are fewer roles which we have been calling artisan, entrepreneur and wizard (including the one we have just added, the specialist collaborator).

In this terminology, an entrepreneur is a scientist who likes to think creatively and to transform his thoughts into funding for his/her research. Typically, that is the role of a professor[15] in an academic setting with a significant research output. Often enough, an entrepreneur does not have time (and may not be interested) to spend hours in the lab or to do the actual calculations. An entrepreneur will rather lead and *manage* a group of students and/or post-docs who will perform the experiments or simulations on the current concepts as seen by and on behalf of the entrepreneur.

This state of affairs has the advantage of allowing the entrepreneur to pursue multiple projects in parallel, by delegating them to individual members (artisans, most likely, or entrepreneurs in the making) of the team. The disadvantage is that as time passes, the entrepreneur becomes progressively more of a manager and less of a scientist, and eventually you may lose contact with the laboratory (which was probably the reason why you decided to become a scientist in the first place). The larger the group the more developed this trend.

An artisan scientist, on the other hand, likes to spend most of the time in the lab, helping students with their experiments or even actually turning the knobs. Someone who gets things done! Occasionally an artisan will help with "administrative" tasks, such as drafting grant proposals. However, the artisan's heart is in the lab, or anyway an artisan strongly prefers turning the knobs, doing the calculations, and so forth. This sort of figure is extremely precious, because an artisan will help supervise graduate students and post-docs and will make sure that things are running smoothly while the entrepreneur is away, teaching or otherwise busy, e.g. raising funds.

Below the artisan in the 'hierarchy' lies the specialist niche scientist, who does not really want any executive responsibility and is happy to be absorbed in a particular specialty, with the occasional publication (as lead author) on the nuts and bolts of the cherished sub-system in (say) the *Review of Scientific Instruments*.

The decision of whether you will aim at being an entrepreneur or an artisan or a specialist is another critical one (just like deciding whether you want to be an experimentalist or a theoretician, or both). You should analyze critically and *coldly* your skills and personality traits, and determine as objectively as possible if your profile better matches an entrepreneur or an artisan or a specialist. If you are in doubt, we advise you to present this issue to colleagues/ friends and get their feedback. You may also want to ask your supervisor, if you are a graduate student. Make sure they understand that this is a sensitive point, and that they should give you an objective answer. Scientists are all born as apprentices and some may grow to be artisans or perhaps wizards; and as long as you work for a supervisor, you will always be an artisan or a tame wizard at most. The question is whether your advisor sees you as a potential leader, i.e. as a future entrepreneur, or as a future wizard or as an artisan. This is an important issue that will strongly affect your career — positively if you choose wisely, negatively otherwise. Do not try to be someone you are not: it would be disastrous. Play in your best role and you will have a much better chance to be happy and even be highly successful.

The North American academic system has evolved through intense competition for research funding as if it were designed to host and promote entrepreneurs almost exclusively — at least for tenured positions (the few that are available). In a university in North America, an artisan in a small group might be called a "*Research Associate*" (see discussion above), but in a larger group might have a more respectable sounding position such as "research professor". These are very respectable positions, and if you decide this is your natural role, there is nothing wrong in seeking this type of job (even though the title of "professor" probably sounds more prestigious). However, you should be aware that — with few exceptions — the salary of a Research Associate typically derives from what is called "*soft money*", i.e., research grant support, which may dwindle away. The position is renewed as long as there is an entrepreneur who brings in funds. It is almost impossible to turn it into a permanent position, so you should not count on long term job security.

In Europe, on the other hand, the academic system is more hierarchical, and groups of professors often work in teams, led by one professor at the top. In such cases, not all team members can be entrepreneurs (for obvious reasons — they would be stepping on each other's toes all the time), and thus the system allows (and to some extent favors) hiring a good number of artisans and wizards into permanent faculty positions. Most other academic systems are similarly hierarchical.

Jobs in industry and government labs, by their very nature, are more appropriate for artisans. In these environments, the management will typically set the objectives and tell you what to do on a short-term, medium-term and long-term basis, and you will be the one turning the knobs and executing the research, first hand. Normally there will be no graduate students to whom one can delegate, but occasionally there can be post-docs (depending on the philosophy of your employer, among other things). In these settings, being an entrepreneur means becoming a manager, and probably doing less and less in terms of research (although again, it is difficult to generalize).

CHOICES IN WORK CLIMATE

In general, doing science and research requires teamwork and coordination (among other things). If the work is done in a team format with a quasi-military hierarchy, there are many roles, such as supreme leader, group leader, team player, outside specialist and (temporary) slave labor (typically undergraduate and graduate students). While most people prefer telling other people what to do, rather than being told, the road to the top job can be arduous, and the leader's job may well become more like that of the president of a small company than that of a scientist *doing science*. If the leader's job seems too political, being a group leader may be a useful compromise. More often in science the work is done in collaborations which are much looser and more democratic, probably less stressful with more room for individual roles in a pleasant group. Things run best when everyone plays a role in which they are at ease. Unfortunately it seems to be the case that the North American (academic) system tends to evaluate everyone as if they were trying to be number ones. Even if Napoleon said that every soldier had the baton of a field marshal in his knapsack, he meant only that the top job was open to anyone with talent, and not that sergeants or junior officers should be judged by their ability to command armies. The European system privileges teamwork and has room for everyone, but North American criteria for promotion and the like often seem to place too much emphasis on the scientist as individual entrepreneur – for better or for worse, it's all about money.

CAPSULE BIOGRAPHIES OF THE AUTHORS

Although this is an aspect that applies mostly to physics, chemistry and materials science (in the sense that it is a basic choice for those fields), there are aspects that apply to other fields, in which one finds a cultural divide between the experimentalists who produce the data about what might be called the "ground truth" (the touchstone by which all theory constructs are tested) - (by analogy with aerial reconnaissance) - and the people who create the theories.

In physics, theorists are very well-known, but in other sciences they are less prominent. Probably the most prominent chemistry theorist in the 20^{th} century was Linus Pauling (Nobelist for the work discussed in "The Nature of the Chemical Bond"). In biochemistry, the best-known examples of what we here term "theoreticians" are the members of the Watson-Crick duo who created the DNA model concept from experimental results.

Federico's viewpoint: As an undergraduate student, I was particularly good at theoretical coursework, and was hoping to become a theoretician as a career. (In several Mediterranean countries, perhaps for cultural or historical reasons, doing theory is considered more popular and prestigious than getting your hands dirty with experimental work. In Italy, most physics students begin by hoping to become theoretical physicists.) This early inclination is also related to the fact that I was (and still am) somewhat clumsy in the laboratory.

As time progressed however, I came to realize that all the best students of my course (and many of them were better than I, at least when comparing primitive indicators of performance such as grades) wanted to become theoreticians as well. Not only that, they all wanted to pursue the theory of high T_c superconductivity, a topic in condensed matter physics that was at the time, — and still is — very hot and controversial and which I also found intellectually engaging.

I was faced with a common kind of dilemma: should I follow my instinct, and become a theoretician, but accept being at the bottom of the list, or at best its middle section? Or should I make a compromise with my feelings and choose to become an experimentalist, perhaps fighting a bit against my inclination, but probably being the best experimentalist in my course? I ended up choosing the latter. It turns out that it has helped my career enormously. At first it was not an easy choice, yet in hindsight it was by far the best choice for me.

The trick to being happy in science, as with life in general, is to know yourself well enough to make the right choices, choices that you will probably have to live with and that may be irreversible. Incidentally, several of my theorist colleagues were also successful so far; however, in the face of tough competition, more than one gifted student who stayed in theory dropped out of graduate school and ended up pursuing a completely different career, like consulting or financial mathematics. This is not necessarily a bad thing of course, and you could argue that perhaps they were not meant to be scientists after all. They may even be happier doing what they are doing now. However, if they had made a different, more rational choice like the one I did, perhaps they would have stayed in science; it is clear that in the event their talent is lost to science. (I know at least one person who wonders what life would have been like if she had stayed in scientific research, and she probably will ask herself that question for a long time hereafter.)

Tudor's viewpoint: My anecdote is almost the reverse. I began as an engineer (actually a hybrid called engineering physics), did an essentially experiment-plus-theory-interpretation engineering thesis at Cambridge University, and began a mixture of theory and experiment in a Research Laboratory doing contract research for the government. Luckily for me, we were actually encouraged to publish (except for certain confidential aspects) in the open literature (probably as a test of the general quality of our work), both by our contractors and by our own leaders. (This made it relatively painless to move into a university position later.) As time went on I realized that there were what I found to be deep mysteries in the experimental technology — vacuum leaks, electrical hum, electrical ground loops, to name the worst — which I could never master and which remained for me always a "wild magic". I gradually but happily abandoned my feeble attempts to master the arcana of the laboratory and became a theoretician, often for experiments in which I had no direct interest, becoming in fact a *de facto* physicist in plasma physics, although holding no degree in physics.

One advantage of this long love affair with experiment is that I retain a deep respect for people who can make experiments work, a lively interest in how experiments are done and how to (in effect) "diagnose" any theoretical constructs to suggest experiments. It gives me a special thrill if I can use theory to show how an experiment that appears not to be working can be saved by using a different protocol and analysis procedure. A theoretician I have become indeed, but a better one for having been also an experimentalist for some ten years.

All this was accomplished with little conscious analysis on my part, without any real penalty, but from this I have become convinced that doing frequent "reality checks" on your comfort level in the way you function in your science is essential. Without this there is a significant risk of drifting into a way of working in which the basic mental discomfort of a poor fit between you and the way you are working leads to a dysfunction in the work for reasons that may pass unperceived.

Federico and Tudor: To place things in perspective and to make this example relevant to scientists in other fields like biology and chemistry, where theory as such may not feature as large, we point out that each discipline has its "hot" subfield. In biology it might be molecular biology, and in chemistry something else.

In the anecdotes just reported we suggest a useful generalization with "hot subfield" replacing "theory".

The lesson to be drawn from the first anecdote thus becomes this. Do not go into the “hot” subfield of your discipline just because it is trendy and all the good students want to do the same. *You* have to choose what is hot for you (Know thyself!). Later, when you become a successful scientist, you may even create a new trend and a new “hot” subfield.

The lesson to be drawn from the second anecdote becomes the following. Just because a field is “hot” is not an absolute reason for going into it, but be aware that the competition will be fierce if you do “jump into the hot water”. So only go into the “hot” field IF BOTH of the following apply: (i) it is sufficiently attractive to you for its intrinsic worth and (ii) you find that you are generating interesting ideas almost in spite of yourself.

FUTURE ARTICLES

In forthcoming articles we will discuss other aspects of scientific ‘survival’. In particular, the next article (third in the series) will discuss what might be termed the actual “game of science” itself: its ecology, how peer review works in practice[16], how things can go wrong, ethical issues associated with it, etc. These last can involve getting proper credit for your work, intellectual property rights and patents, and the like.

Topics in subsequent articles will include: (i) publishing tactics (where and how, journal citation indices and impact factors come into play) together with scientific writing itself and the basic concepts for various types of writing, e.g. a peer-reviewed paper, a thesis, the scientific heart of a research proposal; (ii) how to present and “package” your work so as to become as well-known as you and your work deserve, which involves participation in conferences (which ones and how, oral presentations or posters). Here also are different types of oral presentations such as seminars and job interviews; (iii) How to write your CV in the light of the context in which it will be used, as well as writing applications for scholarships, fellowships and of course research proposals. Getting known in regard to your ideas includes learning how to present your science in grant applications and learning how that differs from composing a peer-reviewed paper.

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2. For those who are not yet familiar with these terms, this means literature for which publication is obtained only through the filter of judgement by their peers in research science (usually through an anonymous review process).
3. The only suggestion we offer on that topic is to work diligently at extending your personal horizons of knowledge and expertise. In the same spirit it is nearly always wise to read widely in science in anything you can understand. Many (but by no means all) of the best opportunities come at the boundaries between disciplines, and the way to be aware of these is to cast the net of your reading as wide as is feasible.
4. This seems to be especially true in North America. In Europe, your peers’ respect is earned by means of a long publication list in prestigious scientific journals. It is rare (though not unheard of) for scientists in Europe to boast about their level of funding.
5. The concept of fame here is very relative and the most famous scientists (such as Albert Einstein) are hardly known at all compared with, say the most famous athletes (such as Tiger Woods). If you meet someone on the street, and ask them who, say, Tiger Woods is, they will probably

know a lot about him, including some of his greatest feats, and even some details of his personal life and advertising. On the other hand, if you ask who Albert Einstein was, they may have a vague notion of a funny scientist who has his tongue sticking out in a picture and who said that everything is relative. They will probably also joke about it, saying that it is quite obvious to them that everything is relative, and that giving a Nobel Prize to someone for such a trivial discovery is an exaggeration. (In case you did not know, Einstein was awarded one Nobel Prize in Physics, in 1921, for his description of the photoelectric effect (published in 1905), but was not awarded a Nobel prize for his work in relativity. In fact, both his theories of relativity, the special and the general one, were not widely accepted by the senior scientific community until long after he formulated them. Now, as a matter of modern technology, General Relativity is an essential element in the programme used for Global Position Satellite (GPS) operation. Far more of us actually use Einstein's general relativity, whether we know it or not, than are affected by anything done by Tiger Woods!)

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