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Craig Loehle
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A science career

Science is a curious profession. It is relatively easy to get into, but much harder to be truly successful at. There are many different paths to success and just as many ways to fail. Many who have an interest in science in school never find their way into a science career. Many who do get an advanced degree in science are never able to get a grant or conduct a successful research program and may leave the field after a while. Some are tempted to cut corners and thus ruin their careers. Even those who have a science job may not be secure in their abilities or their productivity.

This book has four parts. In Chapter 1, science as a career is explored. What do scientists in different fields study? What skills are needed? How do scientists spend their time? How do you choose the right career path? Chapters 2 and 3 cover the ins and outs of creativity and problem solving, the central keys to success in research. Chapter 4 discusses the social dimension of being a scientist.

The most difficult part of a scientist's job is conducting research. Huge amounts of time are wasted in science experiments that fail, ideas that don't pan out, and papers that are never finished. Effort is wasted on proposals that don't get funded and projects whose results are never published. Even published studies are often flawed. Why?

Scientists study science, not psychology, but many of the tricks (and pitfalls) of conducting research are mental. In textbooks a few classic experiments are described (usually only the successful ones) and the student does an apprenticeship (graduate school) with a working scientist. This is not enough. In military training, just learning how to shoot a gun is not enough for an officer. They spend a huge amount of time learning about strategy, tactics, and logistics. But scientists do not. They study calculus and physics and genetics. Yet, for the scientist the

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enemy is much more subtle: disorganization, mental bias, failure of imagination, fear of disapproval, poor time management, etc. These ideas are explored in Chapters 2 and 3 of the book.

In addition to scientists at all levels, others can benefit from this book. Engineers share much with basic scientists and virtually everything in this book applies to their work as well. Those who interact with scientists as employers or in other roles may gain insight into the field. Psychologists may benefit from reading about creativity and cognition as seen by a practitioner of science rather than an artist or musician. Finally, educators can learn about creativity and problem solving from an applied field with an eye toward enhancing science education.

In certain types of problem solving, special skills are learned which are then applied repeatedly. For example, in accounting one learns certain procedures for keeping books and doing computations, but the component skills are specific to a well-defined domain: accounting. In contrast, scientific thinking involves the integration of several types of mental skills and techniques, as well as certain habits and attitudes, in the context of defining the problem to be solved from an initially ambiguous sea of unconnected data, and then solving it. There is an element of risk in scientific problem solving because complexity causes uncertainty. The acquisition of the skills presented in this book, and their integration, will help reduce risk and increase problem solving success.

While there have been many books about creativity and problem solving, they are mostly about problem solving minutiae, such as the use of analogy, visualization, generation of novelty, brainstorming, lateral thinking, and free association. We may say that these component skills are like the ability to saw, the ability to hammer a nail, and the ability to use a drill, without any skill in reading blueprints or an understanding of how an entire house fits together. While a collection of low-level skills will enable you to build a bird house, they do not allow you to build an office building. To make another comparison, brainstorming may help you come up with a name for a new product or an ad campaign slogan, but it will not help you compose a symphony or build a space shuttle. This book goes beyond brainstorming and describes the tools needed for both generating new ideas and for carrying them through to a completed product.

Gardner (1983) proposed that there are discrete dimensions of intelligence, such as linguistic, musical, mathematical, and spatial mental abilities that are relatively independent of one another and

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that are not necessarily measured by a general intelligence quotient (IQ). He points out that IQ mainly measures linguistic and logical/mathematical abilities. Musical aptitude is clearly not tested by IQ tests. I believe there is also a dimension of strategic intelligence. This dimension of intelligence comprises a flair for planning ahead and finding the best route or scenario to obtain an advantageous outcome. A person high on this dimension is good at planning a trip and does not often forget to pack something in his luggage. Such people are likely good at board games and poker (though such games may not motivate them because the outcome seems too trivial), and are also likely to be good at making career moves. The person low on this dimension goes to the laundry without soap, gets in the shower without a towel, and goes to the store without a list. Such a person finds a job but has no concept of a career path. It is really best not to go camping with such a person, because they will end up sleeping in your tent, since they didn't bring any tent pegs. They are usually without a clue and are always getting surprised by outcomes that do not surprise others. Such people go to pieces when faced with logistics problems such as organizing their desk, packing for a trip, or reordering the garage. I believe this dimension is independent of other dimensions of intelligence because I have known otherwise intelligent people who are absolutely incapable of planning ahead or anticipating the consequences of actions. This aspect of intelligence is not very amenable to pencil and paper diagnostic testing, which is why I believe it has not been identified and studied previously. This book explores the strategic dimension of mental reasoning and problem solving in the context of scientific research, where it is a particularly critical skill. Specifically involved in this are the identification of the mind's strengths and weaknesses, understanding how cognitive processes operate, and learning how one can obtain reliable information and solve complex problems, how new ideas are generated and tested, and how real world complexity may be dealt with. This book explores these issues and provides training for the strategic dimension of intellectual reasoning, a key dimension for success but one largely overlooked by our educational system. This book is not an academic treatise, but rather is a guide to applying strategic thinking skills in the context of conducting research.

The importance of strategic thinking can be demonstrated as follows. When the frontal lobes are damaged or removed, the IQ of the person remains unaffected and they may even remain at the genius level if they were at this level before the removal. However, the person loses all initiative and the ability to solve novel problems. They will score

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as well as before in IQ tests, do crossword puzzles and math problems, etc., but will not seek out and solve new problems, such as deciding to remodel the kitchen or invent something. This is exactly the set of symptoms that describes the mindless government official or the corporate drone: they have a college degree and appear smart but they are unable to take initiative and withdraw in fear from novelty. These people have not had an actual lobotomy, but they have been trained and rewarded in such a way that initiative has been squashed. It is not hard to create a drone: merely scoff at all new ideas, have complex procedures that must be followed to the letter, punish mistakes severely, reward conformance, and require approval for every action. The drone can solve simple problems such as accounting problems, arranging meetings, writing a descriptive report, and doing defined technical tasks, as long as the work is defined for them, but they can not create novelty, overcome outdated methods of operating, identify problems with existing systems, or create new concepts or products. For such tasks strategic thinking is required. Technical proficiency and the possession of a college degree is no more a guarantee of strategic thinking than is the IQ score of the lobotomy patient an indicator of their ability to function.

We may further note that the types of problems used in both IQ tests and in most creativity training are contrived and mostly involve the linguistic and logical dimensions of intelligence. The problems typically involve short linguistic riddles (*x* is to *y* as *z* is to what), comparisons, exclusions, analogies, etc., and simple logical operations (short computations). Training in problem solving usually involves simple puzzles such as word problems (a train leaves city P at 10:00 a.m. and . . .). It has been shown, however, that while such tests predict success in school, there is no correlation with success later in life (Gardner, 1983). That is, one can do quite well on standardized tests and get good grades in school, but be incapable of innovation or of dealing with complexity. This is because real life and the production of goods of value requires strategic thinking and creativity, neither of which is either tested by IQ tests or fully developed by current schooling practices, nor is real creativity equivalent to the pure generation of novel responses.

The potential benefit from the application of the information presented in this book is enormous. Gilbert (1978), for example, has documented the huge range of observed productivities among workers. Whether we are looking at academic productivity (publications), computer programming (lines of correct code), artistic output, sales, or any other endeavor, the most productive individual within a job category is often at least 10 times as productive as the average worker, and

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sometimes as much as 30 times. Whereas in the realm of creative output some hold quality up in contrast to quantity, there is actually more often a correlation between the two: the most innovative individuals often produce the most (Simonton, 1988). This is because the same skills that enable truly innovative work to be done also enhance productivity. The success of the individual professional certainly depends on the frequent production of innovative work. Whereas most artists produce a few to a dozen paintings a year, Andy Warhol and Picasso filled warehouses with their work. While most academics write one or two papers per year (or less), some write a book each year. The same applies to inventors, architects, software designers, or any other profession. It applies particularly to research. This difference in productivity is equivalent to that produced by the industrial revolution or the introduction of computers. Might it not be that such high levels of output could be more generally achievable with the right training? In sports, coaching and training regimes have become a science, with the consequence that the range of performance is usually close to 2 or even less (for example, in professional baseball the record for home runs is only twice that of the average major league player). The range of performance on other tasks, being so wide, means that huge improvements in productivity are possible among those who are less productive. The time spent fixing prior mistakes, spinning one's wheels, doing tasks inefficiently, and doing the wrong task add up to an easy potential doubling of productivity for almost anyone doing any type of nonroutine intellectual work. When the quality of the finished product is considered, there is room for further improvement, making an overall increase in value of an order of magnitude within reach for any scientist.

Why do we think that basketball players or tennis players need a coach but no one else does? That intensive training in technique can lead to a top gymnastic performance we do not doubt, but it never seems to occur to us that a top scientific performance can similarly benefit from coaching. And yet, sadly, today one can not count on one's corporation or university to provide such training and productivity enhancement. In the name of keeping costs down, companies have rejected the idea that individuals should be groomed for rapid advancement by providing guidance, feedback, and special work experiences and training. Instead, the idea has become popular that large numbers of employees should be just kept in the job for which they were hired. Many colleges today, for example, use part-time outside instructors for as much as one third of their classes. Such individuals do not receive any career guidance, have no time devoted to research or professional development, do not have laboratory space, can not have graduate students, can not get promoted, and

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are not funded to attend conferences; that is, they are in a dead end job. The same is true in many corporations today, where opportunities for advancement have become few and far between. This style of management makes perfect sense from the short-term bottom line perspective, but the rejection of the concept of training people for advancement is that the entire process of increasing personnel productivity is becoming neglected. In my career, over many years as a software developer and research scientist with six different organizations, not one of my supervisors ever came into my office to ask how the work was going or offered a single tip on how to be more productive, creative, or effective. My sole feedback was at the annual review where I was always told that I was doing just fine and to keep it up. Even if completely true, and not just a cop-out from a boss who wants to avoid the performance appraisal process, such feedback is not very helpful for doing better in the future. Many supervisors actually have a disincentive to providing good career advice: if they increase the productivity of their employees, then the employees will expect a raise or even a promotion, which they have been told will not be provided. In this climate, if the employee (i.e. the reader of this book) is to get ahead, he must become noticeably more proficient, talented, productive, and creative so as to stand out from the crowd. To do this, he needs a coach. This book can be your personal coach in creativity, problem solving technique, work habits, and productivity.

There are three pillars of scientific productivity: skill, motivation, and strategic use of time and effort. Skill is what one acquires in school and what one polishes with practice. This includes facts, manual skills such as mixing of paints for a painter and soldering for an electrician, and technological mastery of such tools as spreadsheets and databases. Skill alone only guarantees one a job doing work for someone else as a cog in the machine of a large organization, but does not guarantee high quality work or outstanding performance. Motivation is a key component of success that is generally not taught in school. Few have succeeded without significant motivation, because success requires sustained and substantial effort. Many motivational books by successful business leaders have been written, and these books can be very helpful for increasing motivation, perseverance, and effort. However, motivation alone is not enough because many unimaginative people put in very long hours doing pointless tasks and producing little of value, and companies full of executives putting in 12-hour days have nevertheless gone bankrupt. The third pillar, strategic use of time and effort, is the ultimate key to success, though it depends on the first two being firmly in place. The strategic dimension is what allows one to choose the right problem to solve, to solve it in a cost-

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effective way, to use resources efficiently, and to be innovative and productive. The strategic dimension, not merely effort, is what accounts for the huge productivity differences noted by Gilbert (1978). In the absence of a concept of strategic use of time, many organizations reward effort rather than output, with the result being that people put in long hours to impress the boss, while being very ineffective in their use of time and perhaps without even producing anything tangible. The combination of skill, motivation, and strategic use of effort can lead to astonishing levels of productivity. This book is based on these three pillars and aims to point the way to such levels of productivity.

One may ask whether strategic thinking alone is sufficient. Of course not. In a world full of downsizing and changing technologies, there is no guarantee of success or of permanent employment. Nor is one always in a position that one's ideas can be carried out. Just because you invent a new product doesn't mean that your company will develop it. However, it is especially under these conditions of uncertainty, where every professional has become a consultant, that optimal output of innovative, high quality work has become most imperative. A number of other issues impact the success of a scientist, including corporate culture, relations with bosses and subordinates, concepts of teaming, and project management. While many of these issues are touched on in this book, the focus is on the performance of the individual: what can you, as an individual, do to become more effective, more innovative, and more productive.

It is useful to contrast this book with Peters and Waterman's *Excellence* (1982), which identified organizational structures and management strategies that have been proven by the test of time (i.e. these companies make money). If you are fortunate enough to work for one of these high performing companies, you will find that the work style promoted in this book will likely be encouraged and the enhanced productivity engendered by these techniques will be rewarded. If you are working for a loser, a company with a bad attitude and a cramped style, then you are probably facing downsizing and need to hone your strategic faculties to get out before you are laid off. If you are a consultant or entrepreneur, then you need this book for your very survival. While Peters and Waterman's book helps one to understand the behavior of the company one works for, most professionals are not in a high enough position to alter the corporate culture. However, one is in complete control of one's own performance. In whatever setting, it is personally better to be creative and productive, even if in the short term it does not seem as if this will be rewarded.

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1.1 WHY SCIENCE?

Nature is a gigantic puzzle, and scientists have the unique opportunity to try to put the pieces together. This process of puzzle solving can be both aggravating and rewarding. It is infinitely interesting and engaging. There is scope for exercising creativity and for self-directed work. While demanding, the work is ultimately rewarding. For me at least, once I have started working on a project, I think about it all the time. Each subproblem that gets solved is both exciting and satisfying.

Making a career in science is not necessarily straightforward, however. The media depictions of scientists are very limited and do not illustrate most of the careers available to scientists, nor do they accurately show what they do all day. There are many possible fields, specialties, and career paths, not just the well-known job of university professor. This chapter introduces the types of tasks that engage scientists, the career paths available to them, and the skills and aptitudes that a scientist needs to have or to develop.

What scientists do

In the popular imagination, scientists make discoveries. While this is part of it, there are actually many activities that scientists engage in that are not "Eureka" moments.

There is often a separation between those who propose a theory and those who test it. This is party due to temperament. The dreamer makes a better theoretician than experimentalist. In addition, once a theory is proposed it can take lots of experiments to test it properly. Who has made the discovery: the one who proposed the theory, or the one(s) who tested it?

A major part of the process of science is the development of methods, tools, and instruments. We can think of remote sensing technology, the electron microscope, and growth chambers as tools that enabled new knowledge to be gathered. The development and testing of such new tools is "science," though it is not a discovery. An additional type of tool is the mathematical or statistical tool. For example, the randomized block experimental design with its accompanying statistical tests is an essential tool in some fields.

The gathering and cataloging of basic data are likewise part of the scientific enterprise. For example, protein databases, catalogs of species, geologic maps, historical climate data, and gene sequences are all useful to the scientific enterprise even though those who collect and maintain this data are not making "discoveries."

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The cases just presented represent the infrastructure of science, the machines, lab techniques, mathematics, and databases that enable discovery. Many scientists spend part or all of their time working on infrastructure, and this work is in fact "science."

Anyone conducting scientific studies must eventually communicate their results in order for them to become part of the common body of knowledge. Thus communication of results is critical. Those who love to do research but hate to write or talk about it will usually fail. There are three principal outlets for communicating scientific results: publications, conferences, and seminars. One only needs a plausible abstract to give a talk at a scientific conference, so talks often represent preliminary or tentative results. Some of this work will never make it into print, and if it is not in print, it does not become part of the body of common knowledge. It is thus best not to fool oneself that a conference talk is an adequate outlet for one's results. Seminars have the advantage that there is more time for questions and discussion, but again, are an impermanent outlet for one's work. Thus scientific publications are a critical avenue for communication of scientific research results.

Sometimes scientists are engaged in practical research. They may be asked not to develop general hydrologic theories, but rather to clarify the hydrology of a particular watershed used for a city's water supply. They may conduct a field survey for an endangered species or do a toxicity test for an industrial chemical. All of these are scientific projects, even though they may add little to basic knowledge. Remember, though, that Pasteur's early work was funded by brewers who wanted to know how to prevent their vats from spoiling.

Some scientific work involves synthesis. Usually in written form, a synthesis draws together a body of knowledge, discusses competing views and conflicting studies, and organizes the subject matter. The classic synthesis is the textbook, but review articles and commentaries also fall into this category. The synthesis of a body of knowledge really is a creative process, though it is sometimes disparaged as "just a literature review."

Large science projects require management. For example, large physics experiments such as colliders or neutrino detectors require huge teams which must be managed. These projects must be managed by real scientists, not by professional managers. It is sometimes believed that an alternative career path for a scientist is to go into management, but this can quickly become an excuse to stop doing science and is no longer a science job.

One might think it is obvious that scientists teach, but generally only academic scientists do so. While the university used to be where most

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scientists spent their career, this is no longer the case. For those who teach, it can consume all their time or be a nice break from the lab and a chance to share their knowledge. Teaching can also be an excuse for not conducting research. Even within a university, many scientists work in research institutes funded by the government, by grants, or by foundations.

Scientists work in groups and they work alone. Ultimately, a scientist must face his experiments and data alone. The average scientist is not a people person. But in the process there are collaborations, both big and small. Often there is a need to combine specialties in order to solve a problem. For example, some wildlife biologists had done field surveys and written up that work. My colleagues and I had some ideas for pulling together landscape data and using it to analyze the field surveys. So, we pulled together all the field people into a loose team, we did the analyses, and everyone was happy (and everyone was a coauthor). I have coauthors that I have never even met. Sometimes very large teams are involved. I was coauthor on a paper with 19 others but this was really quite awkward, because we were all authors rather than having specific subtasks. Some scientists do not work well with others, or always must be in charge. So the way a scientist interacts with colleagues can vary considerably.

As a final note on the types of work that scientists do, the extent to which their work is adventurous varies radically from person to person. An anthropologist may dig up ruins (tedious but mixed with adventure) or study gangs (danger *and* adventure!). On the other hand, he may not go into the field at all. A scientist may work with satellite data (can't visit his instrument), or develop string theory. The extent to which he works with field data, laboratory data, or pure theory will strongly influence his day-to-day work experience.

Careers

In the past, most scientists worked for universities as professors. The Cold War brought big science in the form of the national laboratories, which employed thousands of physicists, chemists, and mathematicians. In addition, public agencies such as the United States Forest Service, National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), Department of Agriculture, and Centers for Disease Control became havens for basic research. Now, therefore, there are all sorts of career paths for scientists, and many of them never come close to a university or government lab.

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