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INTRODUCTION

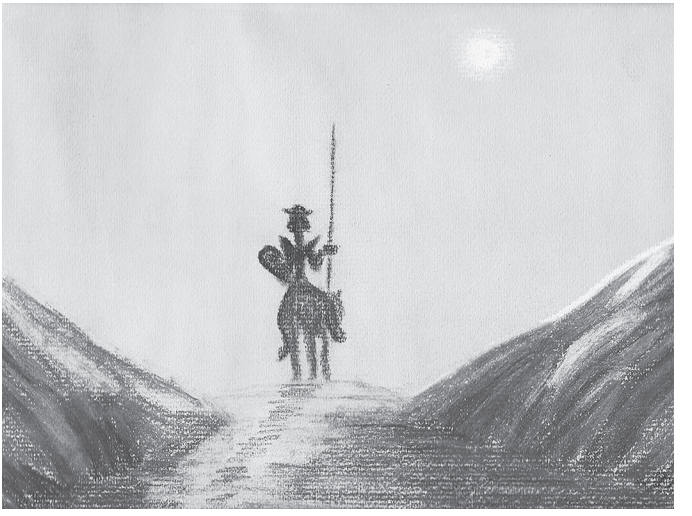

FIGURE 0.1. Don Quixote, by Charles Catania.

Honesty's the best policy.

—MIGUEL DE CERVANTES

THERE ARE TWO IMAGES that hang on the wall of my home office. On one side of the window is a painting of the HMS *Beagle* from Darwin's famous voyage, as the ship enters a cove in Tierra del Fuego. On the other side of the window is a drawing

of Don Quixote riding off into the sunset (see figure 0.1, drawn by my father). The images are reminders of the two main ingredients that go into my research. The picture from Darwin's voyage is a reminder to collect data. The picture of Don Quixote, who imagined himself a knight and jousted with windmills, is a reminder to keep dreaming. Data and imagination, in proper combination, have been key to my life in science.

I never thought I'd have reason to mention these pictures; they are personal reminders of something most scientists seldom discuss or even admit—namely, that there are two sides to the process of discovery. One side of the process is the expected reliance on hypotheses, method, theory, models, statistics, logic, and the like. The other side of the process is far more mysterious and inscrutable. This is the realm of creativity, inspiration, imagination, and the often intangible source of new ideas.

If I had to categorize this book, I would say that it lies somewhere at the intersection of these two different realms of science. It is my best attempt, based on a career spent making discoveries, to distill from the mixture of these two worlds some advice about the craft of doing science. By the craft of science, I mean how to find and solve scientific puzzles while setting yourself up for the fun part—eureka moments when nature reveals one of her secrets.

I'm keenly aware that suggesting an approach to doing science is a bold thing. For most of my career such a project would have been inconceivable in the truest sense of the word. Inconceivable because my own work seemed to follow a chaotic path of exploration punctuated by luck—hardly a style from which to draw lessons. So I should tell you how I got here and why I thought I should write this book.

The seed for this project was a discovery, actually several discoveries, made not in the laboratory, but rather made when I decided to take a break from my experiments to write my last book. The book is called *Great Adaptations*, and it covers many of the studies that I have conducted during my career. These include work on star-nosed moles, shrews, electric eels, snakes, zombie-making wasps, earthworms, and even some strange traditions practiced by humans. The prospect of writing a book is daunting. Before I started writing I did some homework by reading every book of advice I could find on the subject, including William Zinsser's *On Writing Well*, Anne Lamott's *Bird by Bird*, Mary Karr's *The Art of Memoir*, and Jon Franklin's *Writing for Story*, to mention just a few.[1]

I was surprised to feel an immediate kinship with these writers and a connection to their struggles. There's the question of picking the right topic, the mystery of the process, the impossibility of predicting the plot, the idiosyncratic strategies for success, and most especially the ideas that seem to come out of nowhere—at least when things are going well. I experience all of this while doing science. Even the concept of a muse resonates as a metaphor for those special days when, for no obvious reason, the creative process kicks into overdrive.

Perhaps you're skeptical that two such disparate-seeming professions could share experiences? Let me give an example of what it feels like to solve a difficult puzzle after a long period of concentration:

> At one moment I had none of this; at the next I had all of it. If there is any one thing I love . . . more than the rest, it's

> that sudden flash of insight when you see how everything connects. . . . I wrote a page or two of notes in a frenzy of excitement and spent the next two or three days turning my solution over in my mind, looking for flaws and holes . . . but that was mostly out of a sense of this-is-too-good-to-be-true unbelief. Too good or not, I knew it was true at the moment of revelation.

I've had that same feeling many times—it's the very best part of doing science. Except the text above is not from a scientist—it's from Stephen King when he figured out how to finish his book *The Stand*.[2]

So that was the first discovery—finding that doing science shares a surprisingly deep connection with other creative arts. Some background reading taught me that others before me had come to the same conclusion, finding parallels between doing science and writing novels or poetry, painting, composing music, and more.[3] That was not a disappointment, quite the opposite. Knowing that I wasn't the only scientist to have converged on this point spurred me to explore the connections further.

A little more sleuthing, this time on the science side, and it became clear that many other scientists experience the mysterious, inspirational, and often chaotic side of doing science. I'll let some other scientists speak for themselves—here's a sampling taken from specialists in immunology, biology, neuroscience, physiology, and psychology:

> [S]cientists should not be ashamed to admit, as many of them apparently *are* ashamed to admit, that hypotheses appear in their minds along uncharted byways of thought;

that they are imaginative and inspirational in character; that they are indeed adventures of the mind.[4]

—PETER MEDAWAR

Intuition . . . is something subconscious, which, all of a sudden, comes out of the clear sky to you and is absolutely a necessity, more than logic.[5]

—RITA LEVI-MONTALCINI

We seem to forget . . . that some of the most important discoveries have been made without any plan of research . . . that there are researchers who do not work on a verbal plane, who cannot put into words what they are doing.[6]

—CURT RICHTER

All sorts of things can happen when you're open to new ideas and playing around with things.[7]

—STEPHANIE KWOLEK

We believe that such rules as to how science (with a capital S) is done, or should be done, are largely fiction, an attempt to retrospectively codify a process that often amounts to groping. There simply are no rules as to how to do science.[8]

—DAVID HUBEL AND TORSTEN WIESEL

By some unspoken rule, a scientist's feeling of awe for the natural world must be kept under wraps; to acknowledge wonder is tantamount to unreason, and therefore treason.[9]

—SARAH LEWIS

These sound like the musings of poets, not scientists. This is not to suggest that scientists don't eventually work within the confines of a fairly restricted set of rules—what you might call the grammar of science. But this rule-governed behavior may come fairly late in the process. It all starts with an idea about what you might study and how you might study it. To return to the writing comparison, or any other creative endeavor for that matter, as I see it there are two main challenges to success. One is mastering technique. The other is coming up with good ideas about where and how to apply that technique. You may stock a lab with scientific instruments, but there is no ideas store.

Tom McLeish puts it concisely in his book on scientific creativity,[10] suggesting the process of science has two stages—first the conception of an idea, and second the testing of that idea. McLeish is quick to point out: "Look up any popular definition of 'scientific method'—it is exclusively to this second stage that it refers." I'll add that most books on the topic of doing science also deal exclusively with the second stage, leaving out the source of ideas (more on this later). Here again, a comparison with writers is apt. My favorite quote on the topic comes from Stephen King in his memoir on writing: "We are writers, and we never ask one another where we get our ideas; we know we don't know."[11]

That said, whether you are a writer, painter, musician, photographer, or other creative artist, there are certainly some best practices that set the stage for the emergence of new ideas. Stephen King has much to say on this topic when it comes to writing (*his* muse happens to live in the basement, which seems appropriate).

The same is true for science. One of my main goals in this book is to describe some of the ways to set the stage for new ideas and discoveries. In my own case, the intellectual leap from subjective experiences and muses to the concrete world of best practices required turning from Stephen King and his fellow writers to the science philosopher Thomas Kuhn and his landmark work on scientific revolutions. I was influenced not by Kuhn's famous account of revolutionary science and paradigm shifts, but rather by his insightful description of normal day-to-day science, which resonated with my own experience in the lab. That, along with Kuhn's interpretation of what motivates scientists and how experiments in a particular field change over time, helped reveal an underlying pattern in the seeming chaos of many of my own investigations. The pattern (which I describe in chapter 1) is pervasive, at least for me—it underlies most of my discoveries.

That is the origin story for this short book—you might say my recipe included a few sprinkles of electric eels, tentacled snakes, zombie-making wasps, and star-nosed moles, then I added a dash of Thomas Kuhn and a pinch of Stephen King and stirred. Many unexpected insights emerged from the stew. This book also serves as companion to my previous book, *Great Adaptations*, giving the "how" for a series of discoveries. That said, I had to wonder how much of my process, exploring extreme adaptations at the fringes of biology and neuroscience, would be useful in the wider world of science.

Here again books about writing were encouraging, this time not for their content, but rather for their sheer number and diversity. If you do a little searching, you will find that aspiring writers have vast resources upon which to draw for

advice and inspiration—my shelf holds over two dozen books on writing. When I asked a friend about their own collection, they sent me a photo of their bookshelf because the list was too long to type. These books are like candy to anyone contemplating a writing project.

What could possibly be useful about so many different perspectives on writing? It allows people to adopt a strategy that I believe is key to success in almost every walk of life. Namely, you can learn about the vast diversity of successful approaches to a difficult endeavor, reject those that don't align with your own skills and personality, and adopt the approaches that work best for you. For example, some writers insist that outlining a project ahead of time is essential (Jon Franklin); others reject this strategy as a constraint on the imagination (Stephen King). As you might imagine, the pool of ideas for how to approach a writing project is broad and deep.

That same selective process—that is, finding out which strategies and approaches work best for you—applies to science as well. The problem is, there are far fewer accounts of how science gets done. And by this I don't mean books about data analysis, framing hypotheses, grant writing, lab management, or the statistical basis of experimental design. Many such books exist, but they mostly focus on what Tom McLeish called the second stage of science—the testing stage. What about the more personal account of how scientists come up with ideas, approach new problems, and stay motivated—not to mention what goes wrong and how they fail? I have only a handful of such books on my shelf, and it's telling that one is from the 1800s. To mention a few of the few, there's E. O. Wilson's *Letters to a Young Scientist* (2013),[12] Medawar's *Advice*

to a Young Scientist (1979),[13] and Santiago Ramón y Cajal's ancient, but still popular, *Advice for a Young Investigator* (first published in 1897).[14] There is clearly a need for more perspectives on how to approach science. Hence my decision to persevere and put some of my own practices down for the record.

I will often compare the process and experience of doing science with that of writing. Sometimes it's not a comparison per se, because scientists must write (see chapter 4). But even outside the writing domain, there are many analogous challenges and solutions shared by these two creative endeavors. I think the ideas are more tractable when you can see how they apply equally to such seemingly different vocations.

At the same time, I will try to convey some of the specific practices and strategies that have helped me to solve scientific puzzles, design experiments, make unexpected discoveries, put discoveries in context, search for beauty in the data, and deal with failures along the way. Although I have included many different examples of studies that support the ideas I will present, the most detailed accounts and the majority of the figures come necessarily from my own work. I hope it will be obvious from what follows that I am not advocating for a particular approach to something as complex and diverse as science. Rather, my goal is to add a little something to the ideas pool. I hope you find something to absorb.

P.S. The QR codes that accompany some of the book's figures link to movies related to a figure or topic. Scan the code with your phone (or, in the ebook, click on the code block) to access the videos.

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