How to Write & Publish a Scientific Paper

3rd EDITION

by Robert A. Day

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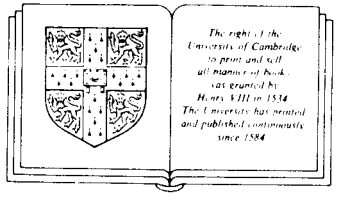

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In most of mankind gratitude is merely a secret hope for greater favours. —Duc de la Rochefoucauld

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Like a cookbook, a "how to" book presents many recipes that the author has collected over the years. A few of the recipes may be original. Some may be variations of someone else's originals. Many of the recipes in such a collection, however, are "borrowed" intact from other sources.

In this book, I have done a reasonable job, I think, in citing the sources of material borrowed from the published literature. But how about the many ideas and procedures that one has picked up from discussions with colleagues? After the passage of time, one can no longer remember who originated what idea. After the passage of even more time, it seems to me that all of the really good ideas originated with me, a proposition that I know is indefensible.

I am indebted to my friends and colleagues who served with me on the Publications Board of the American Society for Microbiology during the 19 years I served that Society. I am also grateful to the Society for Scholarly Publishing and the Council of Biology Editors, the two organizations from which I have learned the most about scientific writing and publishing.

I am grateful to a number of colleagues who have read the manuscript for this Third Edition and offered valuable comments: L. Leon Campbell, Barton D. Day, Robin A. Day, Linda Illig, Evelyn S. Myers, Maeve O'Connor, Nancy Sakaduski, Alex Shrift, Rivers Singleton, Jr., and Robert Snyder. I am especially grateful to Betty J. Day for help in this as in all things.

Preface

The man of science appears to be the only person who has something to say just now, and the only man who does not know how to say it. — Sir James Barrie

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The goal of scientific research is publication. Scientists, starting as graduate students, are measured primarily not by their dexterity in laboratory manipulations, not by their innate knowledge of either broad or narrow scientific subjects, and certainly not by their wit or charm; they are measured, and become known (or remain unknown), by their publications.

A scientific experiment, no matter how spectacular the results, is not completed until the results are published. In fact, the cornerstone of the philosophy of science is based on the fundamental assumption that original research *must* be published; only thus can new scientific knowledge be authenticated and then added to the existing data base that we call scientific knowledge.

It is not necessary for the plumber to write about pipes, nor is it necessary for the lawyer to write about cases (except *brief* writing), but the research scientist, perhaps uniquely among the trades and professions, must provide a written document showing what he or she did, why it was done, how it was done, and what was learned from it. The key word is *reproducibility*. That is what makes scientific writing unique.

Thus the scientist must not only "do" science but must "write" science. Bad writing can and often does prevent or delay the publication of good science. Unfortunately, the education of scientists is often so overwhelmingly committed to the technical aspects of science that the communication arts are neglected or ignored. In short, many good scientists are poor writers. Certainly, many scientists do not like to write. As Charles Darwin said, "a natural-

ist's life would be a happy one if he had only to observe and never to write" (quoted by Trelease [47]).

Most of today's scientists did not have the chance to undertake a formal course in scientific writing. As graduate students, they learned to imitate the style and approach of previous authors. Some scientists became good writers nonetheless. Many, however, learned only how to repeat all that is incorrect with respect to the prose and style of the authors before them, thus establishing a system of error in perpetuity.

The purpose of this book is to help scientists and students of the sciences in all disciplines to prepare manuscripts that will have a high probability of being accepted for publication and of being completely understood when they are published. Because the requirements of journals vary widely from discipline to discipline, and even within the same discipline, it is not possible to offer recommendations that are universally acceptable. In this book I present certain basic principles that are accepted in most disciplines.

The development of this book began some 30 years ago when I taught a graduate seminar in scientific writing at the Institute of Microbiology at Rutgers University. I quickly learned that graduate students in the sciences both wanted and needed *practical* information about writing. If I lectured about the pros and cons of split infinitives, my students became somnolent; if I lectured about how to organize data into a table, they were wide awake. For that reason, I used a straightforward "how to" approach when I later published an article (22) based on my old lecture notes. The article turned out to be surprisingly popular and that led naturally to the publication of the First Edition of this book.

And the First Edition led naturally to the Second Edition and now to the Third Edition. Because this book is now being used in teaching programs in several hundred colleges and universities, it seems desirable to keep it up to date. I thank those readers who kindly provided me with comments and criticisms of the previous editions, and I herewith invite additional suggestions and comments that may improve future editions of this book.

Although this Third Edition is larger and better (he says) than the earlier editions, the basic outline of the book has not been altered. Because the reviews of the previous editions were almost universally favorable, drastic revision seemed unwise. And the reviews *were* favorable. One reviewer described the book as "both good and original." Unfortunately, he went on to add (quoting

Samuel Johnson) that "the part that is good is not original and the part that is original is not good." Several other reviewers compared my writing style with that of Shakespeare, Dickens, and Thackeray—but not favorably. Another reviewer said "Day is a writer for the ages—for the ages of four to eight."

Without meaning to knock the competition, I should observe that my book is clearly a "how to" book, whereas most other books on the subject of scientific writing are written in more general terms, with emphasis on the language of science. This book was written from the perspective of my many years of experience as a managing editor, as a publisher, and as a teacher. Thus, the contents are specific and practical.

In writing this book, I had four goals in mind. First, I delayed writing and publishing it until I was reasonably sure that I would not violate the managing editors' creed: "Don't start vast projects with half-vast ideas." Second, I wanted to present certain information about the scientific paper itself and how to cook it. (Yes, this *is* a cookbook.) Third, although this book is in no sense a substitute for a course in English grammar, I do comment repeatedly on the use and misuse of English, with such comments interspersed throughout a number of the chapters and with a summary view of the subject in a later chapter. Fourth, because books such as this are usually as dull as dust, dull to read and dull to write, I have also tried to make the reader laugh. Scientific writing abounds with egregious bloopers (what the British sometimes call "bloomers"), and through the years I have amassed quite a collection of these scientific and grammatical monstrosities, which I am now pleased to share. I have tried to enjoy writing this book, and I hope that you will enjoy reading it.

Note that I say "reading it," even though earlier I described this book as a cookbook. If it were simply a book of recipes, it would hardly be suitable for cover-to-cover reading. Actually, I have tried to organize this material in such a way that it reads logically from start to finish, while at the same time it provides the recipes needed to cook the scientific paper. I hope that users of this book might at least consider a straightforward reading of it. In this way, the reader, particularly the graduate student and fledgling writer, may get something of the flavor of just what a scientific paper is. Then, the book can be used basically as a reference whenever questions arise. The book has a detailed subject index.

In the first two chapters (new to this edition), I try to define how scientific writing is different from other forms of writing and how history has brought this about.

In the third chapter, I attempt to define a scientific paper. To write a scientific paper, the writer *must* know exactly *what* to do and *why*. Not only does this make the job manageable, but this is precisely the knowledge that the practicing scientist must have, and always keep in mind, to avoid the pitfalls that have ruined the reputations of many scientist authors. To be guilty of dual publication, or to use the work of others without appropriate attribution, is the type of breach in scientific ethics that is regarded as unforgivable by one's peers. Therefore, exact definition of what may go into a scientific paper, and what may not, is of prime importance.

In the next nine chapters, each individual element of the scientific paper is analyzed, item by item. A scientific paper is the sum of its component parts. Fortunately, for student and practicing scientist alike, there are certain commonly accepted rules regarding the construction of the title, the Abstract, the Introduction, and the other main parts of the paper, so that these rules, once mastered, should serve the scientist throughout his or her research career.

In later chapters, associated information is given. Some of this information is technical (how to prepare illustrative material, for example) and some of it is related to the post-writing stages (the submission, review, and publishing processes). Then, briefly, the rules relating to primary scientific papers are adjusted to fit different circumstances, such as the writing of review papers, conference reports, book reviews, and theses. Chapters 24 and 25 present information about oral presentations and (new to this edition) poster presentations. Finally, in the last four chapters, I present some of the rules of English as applied to scientific writing, a sermon against jargon, a discussion of abbreviations, and a sermon against sin.

At the back of the book are six appendixes, the Glossary of Technical Terms (new to this edition), the References, and the Index. As to the references, note that I have used two forms of citation in this book. When I cite something of only passing interest—e.g., a defective title of a published article—the citation is given briefly and parenthetically in the text. Articles and books containing substantial information on the subject under discussion are cited by number only in the text, and the full citations are

given in the References at the back of the book. Serious students may wish to consult some of these references for additional or related information.

I do not have all the answers. I thought I did when I was a bit younger. Perhaps I can trace some of my character development to the time when Dr. Smith submitted to one of my journals a suprisingly well-written, well-prepared manuscript, his previous manuscripts having been poorly written, badly organized messes. After review of the new manuscript, I wrote: "Dr. Smith, we are happy to accept your superbly written paper for publication in the *Journal.*" However, I just couldn't help adding: "Tell me, who wrote it for you?"

Dr. Smith answered: "I am so happy that you found my paper acceptable, but tell me, who read it to you?"

Thus, with appropriate humility, I will try to tell you a few things that may be of use in writing scientific papers.

In the Preface to the First Edition, I stated that I would "view the book as a success if it provides you with the information needed to write effective scientific papers and if it makes me rich and famous." Having since achieved neither fame nor fortune, I nonetheless continue to hope that this book is "a success" for *you*, the reader.

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Chapter 1
What Is Scientific Writing?

Beauty of style and harmony and grace and good rhythm depend on simplicity. —Plato

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THE NEED FOR CLARITY

What is scientific writing? I believe that the key to scientific writing is clarity. Successful scientific experimentation is the result of a clear mind attacking a clearly stated problem and producing clearly stated conclusions. Ideally, clarity should be a characteristic of any type of communication; however, when something is being said *for the first time,* clarity is essential. Most scientific papers, those published in our primary research journals, are accepted for publication precisely because they *do* contribute *new* knowledge. Hence, we should demand absolute clarity in scientific writing.

RECEIVING THE SIGNALS

Most people have no doubt heard this question: If a tree falls in the forest, and there is no one there to hear it fall, does it make a sound? The correct answer is no. To understand this, we need to consult a dictionary. *Webster's Ninth New Collegiate Dictionary* gives as the first two definitions of "sound": "1 *a*: the sensation perceived by the sense of hearing *b*: a particular auditory impression." Thus, sound is more than "pressure waves," and indeed there can be no sound without a hearer.

And, similarly, scientific communication is a two-way process. Just as a signal of any kind is useless unless it is perceived, a published scientific paper (signal) is useless unless it is both re-

ceived *and* understood by its intended audience. And, if we accept the analogy of "sound" as being sound, we can restate the axiom of science as being: A scientific experiment is not complete until the results have been published *and understood.* Publication is no more than "pressure waves" unless the published paper is understood. Too many scientific papers fall silently in the woods.

UNDERSTANDING THE SIGNALS

Scientific writing is the transmission of a clear signal to a recipient. The words of the signal should be as clear and simple and well-ordered as possible. In scientific writing, there is no room for and no need for ornamentation. The flowery literary embellishments, the metaphors, the similes, the idiomatic expressions, are very likely to cause confusion and should seldom be used in writing research papers.

Science is simply too important to be communicated in anything other than words of certain meaning. And that clear, certain meaning should apply to not just peers of the author, but also to students just embarking on their careers, to scientists reading outside their own narrow discipline, and *especially* to those readers (the majority of readers today) whose native language is other than English.

Many kinds of writing are designed for entertainment. Scientific writing has a different purpose: to communicate new scientific findings. Scientific writing should be as clear and simple as possible.

LANGUAGE OF A SCIENTIFIC PAPER

In addition to organization, the second principal ingredient of a scientific paper should be appropriate language. In this book, I keep emphasizing proper use of English, because most scientists have trouble in this area. We must all recognize that "English has very nearly become the universal language of science" (E. Garfield, *The Scientist,* 7 Sept. 1987, p. 9). All scientists must learn to use the English language with precision.

If scientific knowledge is at least as important as any other knowledge, it must be communicated effectively, clearly, in words of certain meaning. The scientist, to succeed in this endeavor, must therefore be literate. David B. Truman, when he was Dean of Columbia College, said it well: "In the complexities of contem-

porary existence the specialist who is trained but uneducated, technically skilled but culturally incompetent, is a menace."

Although the ultimate result of scientific research is publication, it has always amazed me that so many scientists neglect the responsibilities involved. A scientist will spend months or years of hard work to secure data, and then unconcernedly let much of their value be lost because of lack of interest in the communication process. The same scientist who will overcome tremendous obstacles to carry out a measurement to the fourth decimal place will be in deep slumber while a secretary is casually changing micrograms per milliliter to milligrams per milliliter and while the compositor slips in an occasional pounds per barrel.

English need not be difficult. In scientific writing, we say: "The best English is that which gives the sense in the fewest short words" (a dictum printed for some years in the "Instructions to Authors" of the *Journal of Bacteriology*). Literary tricks, metaphors and the like, divert attention from the substance to the style. They should be used rarely, if at all, in scientific writing.

Chapter 2
Origins of Scientific Writing

For what good science tries to eliminate, good art seeks to provoke—mystery, which is lethal to the one, and vital to the other.
—John Fowles

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THE EARLY HISTORY

Human beings have been able to communicate for thousands of years. Yet scientific communication as we know it today is relatively new. The first journals were published only 300 years ago, and the IMRAD (Introduction, Methods, Results, and Discussion) organization of scientific papers has developed within the past 100 years.

Knowledge, scientific or otherwise, could not be effectively communicated until appropriate mechanisms of communication became available. Prehistoric people could communicate orally, of course, but each new generation started from essentially the same base line because, without written records to refer to, knowledge was lost almost as rapidly as it was found.

Cave paintings and inscriptions carved onto rocks were among the first human attempts to leave records for succeeding generations. In a sense, today we are lucky that our early ancestors chose such media because some of these early "messages" have survived, whereas messages on less-durable materials would have been lost. (Perhaps many have been.) On the other hand, communication via such media was incredibly difficult. Think, for example, of the distributional problems the U.S. Postal Service would have today if the medium of correspondence were 100-lb rocks. They have enough troubles with ½-oz letters.

The earliest book we know of is a Chaldean account of the Flood. This story was inscribed on a clay tablet in about 4,000 B.C., antedating Genesis by some 2,000 years (48).

A medium of communication that was light weight and portable was needed. The first successful medium was papyrus (sheets made from the papyrus plant and glued together to form a roll sometimes 20 to 40 ft long, fastened to a wooden roller), which came into use about 2,000 B.C. In 190 B.C. parchment (made from animal skins) came into use. The Greeks assembled large libraries in Ephesus and Pergamum (in what is now Turkey) and in Alexandria. According to Plutarch, the library in Pergamum contained 200,000 volumes in 40 B.C. (48).

In 105 A.D. the Chinese invented paper, the modern medium of communication. However, because there was no effective way of duplicating communications, scholarly knowledge could not be widely disseminated.

Perhaps the greatest single invention in the intellectual history of mankind was the invention of the printing press. Although movable type was invented in China in about 1100 A.D. (48), the Western World gives credit to Gutenberg, who printed his 42-line Bible from movable type on a printing press in 1455 A.D. Gutenberg's invention was effectively and immediately put to use throughout Europe. By the year 1500, thousands of copies of hundreds of books (called "incunabula") were printed.

The first scientific journals appeared in 1665, when coincidentally two different journals commenced publication, the *Journal des Scavans* in France and the *Philosophical Transactions of the Royal Society of London* in England. Since that time, journals have served as the primary means of communication in the sciences. Currently, some 70,000 scientific and technical journals are published throughout the world (30).

THE IMRAD STORY

The early journals published papers that we call "descriptive." Typically, a scientist would report that "First, I saw this, and then I saw that" or "First, I did this, and then I did that." Often the observations were in simple chronological order.

This descriptive style was appropriate for the kind of science then being reported. In fact, this straightforward style of reporting is still used today in "letters" journals, in case reports in medicine, and in geological surveys, etc.