COMMUNICATING SCIENCE

A Practical Guide for Engineers and Physical Scientists

Raymond Boxman • Edith Boxman

World Scientific

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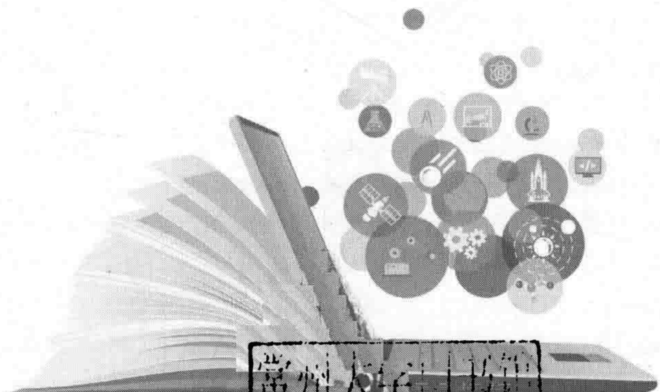

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Preface

Ray Boxman: The unlikely story of this book begins with my early elementary school education in the days when students were issued stubby pencils without erasers and paper that seemed to have hunks of wood sticking out of it. I was known as "Mr. X" because of all of the corrections I needed to make. Nonetheless, I was accepted by each of the universities to which I applied, except the one that required a writing sample. Upon completion of my PhD thesis, the more junior of my supervisors reviewed the thesis and commented that he liked it, but suggested that it should be written in the present tense. I dutifully revised the text and submitted it to my senior supervisor, who also commented that he liked it, but suggested that it should be written in the past tense. In those days, way before the era of personal computers and word processors, revisions involved a great deal of retyping on a manual typewriter. I solved the dilemma by locking both professors in one room, and announcing that I would not release them until they agreed on the proper tense.

After receiving a faculty appointment at Tel Aviv University, I improved my writing, with some helpful mentoring by senior faculty in my department, notably the late Prof. Enrico Gruenbaum (whose native language was not English). I published many papers and thus did not perish in academia.

In 1997, the Dean of the Faculty of Engineering presented me with a problem. Recently, the faculty had changed its regulations to require all Ph.D. students to submit their theses in English. The motivation was to widen the basis for finding referees. However, these referees complained about the level of the English.

The Dean didn't know about my past identity as Mr. X. Also, his motivation in tossing this hot potato to me may not have been totally pure. Although I had certainly published and edited, and English is my native language, I had no prior experience in teaching English or writing. The university had a foreign languages division which previously had taught the faculty's Ph.D. students, but the faculty paid for this service. Because of interdepartmental squabbling about the right to teach various electrical engineering courses, I had a light teaching load, so throwing me the hot potato would save the faculty some money.

I accepted the challenge and examined some of the students' work, and the referees' comments. I quickly concluded that while there was an "English" problem, there was a much bigger underlying problem of poor organization and poor writing that was often connected to poor scientific thinking. The result in any language would be poor.

The course I organized emphasized the organizational aspects of writing theses and journal papers, using Weissberg and Buker's excellent text *Writing-up Research*. Much to my surprise, the students loved the course, as did their thesis supervisors. Frequently, I received feedback from the students that this was the most valuable course in their doctoral studies. Students reported comments from reviewers that their papers were well written and well organized. Some students even received best-paper awards. Furthermore, the students' thesis supervisors felt that their burden was lessened, and some even reported that they learned useful hints from their students. I taught the course for sixteen years, until I reduced my teaching load nearing retirement. Perhaps the Dean's decision to throw this hot potato to an engineer and the former Mr. X had some merit.

Edith Boxman adds: My introduction to scientific writing and editing was proofreading Ray's doctoral thesis. I swore I would never again read any scientific paper by Ray or anyone else. However, in my own work, as an economist and banker, I was frequently asked to translate and edit documents written by my colleagues. These requests, I could not refuse, especially since many of these colleagues were kind enough to edit the documents I wrote in Hebrew. My threat in the early years of our marriage never to review a scientific paper again was forgotten as I wrote business plans for some of Ray's commercial ventures and became increasingly involved in developing materials for supplemental writing courses.

And from us both: In response to several requests from Ray's colleagues, we jointly developed a 12-hour short course on scientific writing, which we subsequently presented at the Aachen Technical University, Ariel University, Istituto Nazionale Fisica Nucleare – Universita Degli Studi di Padova, Kazan State Technological University, the Leibniz Institute for Plasma Science and Technology, Northwestern

University, University of Canterbury, University of Sydney and Xian Jiaotong University.

Our teaching experience provided the impetus and motivation for this text. We wanted a short text that emphasizes the connection between scientific thinking and writing. We wanted a text aimed at engineers and scientists, written from an engineer's perspective. We wanted a text that every Ph.D. student would want to read before writing his or her thesis. And we wanted a resource to which researchers would return as they advanced in their careers. We hope that this text fulfills at least some of these goals.

We are grateful for all of the help and encouragement we received during the course of writing this book. First and foremost, we thank all of our students. The adage that you learn from your students is certainly true for us. Our students' enthusiasm to learn has inspired us. Many of the examples in this text are based on the exercises of students who gave their permission to use their material anonymously. We thank RB's colleagues in the Electrical Discharge and Plasma Lab, Issak Beilis, Nahum Parkansky, and Dan Gazit, as well as students in the lab, whose work inspired many of the examples in the text. We gratefully acknowledge Orna Hamilis, who prepared the illustrations.

Many colleagues, family members, friends, and former students suggested examples or reviewed all or parts of *Communicating Science*. We thank Andre Anders, Benjamin Boxman, Jonathan Boxman, Lillian Boxman, Ian Falkoner, Joyce Friedler, Evgeny Gidalevich, Rami Haj-Ali, Daniel Haney, Azriel Kadim, Simon Kahn, Michael Keidar, Juergen Kolb, Shalom Lampert, Emma Lindley, Zhiyuan Liu, Boris Melamed, Judith Posner, Daniel Prober, Yossi Shacham, Zhiyuan Sun and Sharyn Weisman, for their useful suggestions, and for catching embarrassing mistakes. We, of course, take responsibility for those that remain.

Raymond and Edith Boxman
Herzliya, Israel, April 2016

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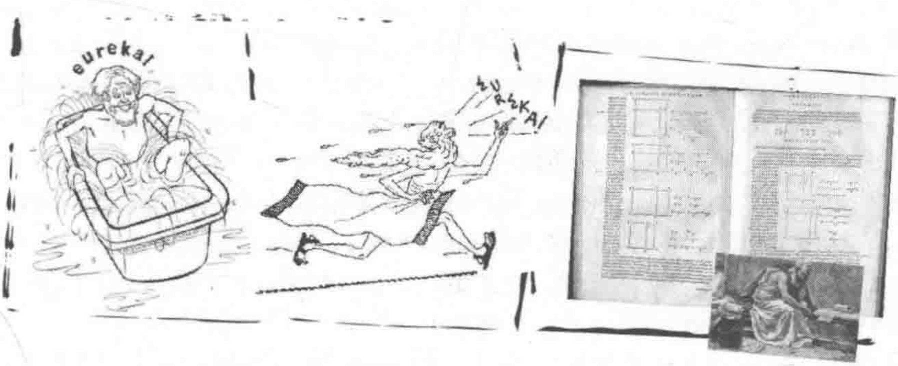
Chapter 1

Introduction



The ancient Greek mathematician and physicist, Archimedes (287–212 BCE), is said to have run naked through the streets of his native Syracuse shouting Eureka after he discovered, while bathing, the principle of buoyancy which bears his name. This rather unorthodox method of communicating science and technology was supplemented by the more conventional method of writing up his research. Archimedes' research on mechanics and geometry has influenced the scientific community to this day.

Archimedes was a member of a scientific community which was spread throughout the world known to him. He corresponded with colleagues including Conan of Samos and Eratosthenes of Cyrene. The results of one member of the community provided a basis for new results by others. The tradition of communicating among members of the scientific community facilitates synergy among scientists and has led to a rate of scientific progress which would be inconceivable if each had worked in isolation. Thus global communication among scientists has most importantly an altruistic function — furthering science and technology.

Secondarily, the communication of science and technology within the scientific community furthers the reputation and career of the scientist-communicator. It is not only what you do but also how you present it that influences the opinions of evaluators.

Close links between science and government and the need to communicate science to non-experts are by no means new. In his famous run in Syracuse, Archimedes was not headed to a scientific symposium of his colleagues but rather to his patron, King Hiero II. The king had commissioned Archimedes to solve a very practical problem with diplomatic implications — how to determine the gold content of a gift crown of irregular shape without damaging it.

In modern times, scientists and engineers need to communicate with:

(1) the scientific community, to share their research results and to participate in the global effort to advance science and technology;
(2) the public sector, to gain sponsorship and to influence policy;
(3) the business community, to convert research results into commercial products and services which can benefit consumers, and thereby benefitting investors and business backers; and
(4) the general public, to encourage the support of the taxpayer who ultimately bears much of the cost of scientific research and development.

A research report is a communications channel, analogous to a TV broadcast channel, in which the writer is the transmitter and the readers are the receivers. As in broadcasting, there are hopefully many receivers (readers) but only one transmitter (the writer). The transmission is one-directional; the transmitter has no possibility of receiving feedback, requests for clarification or repeat transmissions. To successfully communicate with the receivers, the transmitter uses a protocol, frequency, power level, etc. suitable to the receiver, which must take into account limitations of the media and the receivers. Considerable resources and expense are expended on the transmitter so that relatively simple, inexpensive receivers can be used.

Similarly, the skilled scientific writer uses conventions which the reader expects and endeavors to present the topic in a way that is easy for the reader to understand. The writer must expend much effort so that the readers' task is easy. Good scientific and technical writing is easy for reader to understand but not necessarily easy for the writer to write.

The communication conventions are very much a product of the culture in which they exist. The style and organization of a paper today in the *Journal of Applied Physics* is decidedly different from that used by Archimedes in the classical Greek world.

This guide is intended to assist researchers and graduate students to write theses and journal papers, to prepare lectures and posters, and to communicate through other genres that they are likely to encounter in their professional careers. It provides "recipes" for these genres which are suitable for today's scientific global village. Grammatical and stylistic suggestions are provided specifically for English, but the organizational guidance is equally applicable throughout western scientific culture.

Good scientific communication requires good underlying scientific thinking. Moreover, the process of communicating can sharpen scientific thinking. This book will emphasize this connection.

The "recipes" provided in this book are not hard and fast rules. Many writers produce excellent papers by modifying their style to suit particular content, or they develop a personal style while remaining within the broad conventions used in communicating science. Others deviate from these rules with poor results and yet their work is published. However, the recipes suggested herein will always produce well-organized documents. They will provide the inexperienced writer with a solid starting point.

Typically, researchers and technologists spend 20% of their time writing research reports, proposals and other communications, but few receive formal training in writing. Furthermore, writing often does not come naturally to scientists and engineers, and is often viewed as an unwanted chore and a distraction from actually performing research and development. Nonetheless, writing is a skill that can be learned. With improved skill, the quality of the communications is improved, the effort required is reduced, and the reputation of both the writer and the writer's institution is enhanced.

For speakers of English as a second language, global communication may seem especially challenging. It may be helpful to realize that English in scientific papers is relatively straightforward compared to that in general literature. Scientific writing uses limited vocabulary and grammatical forms, it is conventional and the emphasis is on clarity and not on linguistic gymnastics.

This book is organized first into chapters devoted to particular writing genres, and then is followed by a chapter devoted to composition, style, and English usage which is applicable to all genres.

Chapters 2–5 present genres used within the research community:

- Chapter 2 presents the "research report", which includes theses, journal papers, and internal company reports. This chapter is central to the book, as writing research reports is the most common communications task for researchers, and the other genres contain analogous elements. The concepts developed in this chapter will be used in the subsequent chapters.
- Chapter 3 discusses the journal publication process.
- Chapter 4 discusses conference presentations, both short lectures and posters, as well as suggestions for getting the most out of conference attendance.
- Chapter 5 presents research proposals. Researchers must write successful proposals to advance into leadership positions.

Chapters 6–9 concern communications genres which connect scientists and engineers with the wider community. Chapters 6 and 7 are intended for scientists and engineers interested in commercializing their research results.

- Chapter 6 presents the business plan, a document which organizes the business approach of entrepreneurs, and facilitates evaluation by potential investors.
- Chapter 7 discusses patents and patent applications.

- Chapter 8 discusses reports in popular media.
  Because business plans, patent applications, and press releases are usually prepared by or with the assistance of professionals, the main objective of these chapters is to explain their content and organization so that the interaction between the researcher and professional patent preparer, business analyst, or publicist will be effective.
- Chapter 9 presents business correspondence, curricula vitae and résumés, as well as some suggestions for job hunting.

Finally, Chapter 10 provides general writing guidelines, including writing strategies, English grammatical structures common in scientific communications, and some tips for non-native English speakers.

Chapter 2

Research Reports: Journal Papers, Theses, and Internal Reports

2.1 Definition and Scope

The research report is a complete report of a scientific finding to the scientific community. It specifies how the finding was obtained in sufficient detail to allow duplication elsewhere. It places the work in scientific context by reviewing previous scientific work and by interpreting the current results in view of the most relevant preceding studies. The research report is the most important instrument by which scientists and engineers communicate the results of their research to their professional colleagues.

The research report is distinguished from the abbreviated research report by its completeness. Abbreviated research reports, which include letters, brief communications, and many conference papers, do not necessarily provide all details needed for duplication or for placing the work in its scientific context. Abbreviated research reports will be described briefly towards the end of this chapter, in section 2.13.

Primarily, the purpose of the research report is to share research results with colleagues. Colleagues may be in a restricted circle in the case of an internal report, or throughout the global scientific community in the case of a journal paper. In so doing, the researcher becomes a member of a team, either a restricted team whose objective is to advance the interests of an institution or a loosely defined global team whose objective is to advance knowledge. Secondarily, a good research report enhances the reputation of the researchers who write the report, and the organization in which they work.

The same basic structure is used for various types of research reports, including theses, journal papers, and internal reports. This structure is applicable across a wide spectrum of fields including engineering, physical sciences, life sciences, and social sciences. All experimental and quasi-experimental research reports (e.g. numerical experiments and public opinion surveys) use the same structure. Theoretical papers use a slightly different structure, and there is more variance in presentation among them, but they also share the same basic principles. This chapter explains the structure of the research report and the content of the various sections. It describes style and grammatical conventions relevant to the various sections of the report. Examples of key sentences, as well as the key conventions, are provided.

2.2 Before Beginning to Write

2.2.1 *Research question*

Good research reports revolve around a research question, the question which is answered by the research report. In some fields such as biology or medicine, the research question is stated formally. In engineering and the physical sciences, the research question does not appear explicitly as part of the paper, but is implicitly stated in the statement of purpose (stage 4 of the Introduction, described in section 2.4.4 below) and explicitly answered in the Conclusions (described in section 2.9).

Most likely, a research question was defined when the research was first proposed. If so, review it to determine if the results obtained in fact answer the question. The question may be revised, as necessary, to reflect more accurately what was actually answered by the research. If a research question was not previously defined, formally state the research question before beginning to write the research report, and use it to guide all aspects of the writing.

The research question should be explicit, succinct, and as broad or (more likely) narrow as the actual results obtained. Formulate it as a grammatical question, i.e. it must demand an answer and be terminated by a question mark (?). Examples of research questions are presented in Table 2.1.

Table 2.1. Examples of research questions (RQs). All of the examples in the left column are structurally correct, and can describe a particular research project. The right column analyzes each example, and, where appropriate, suggests alternatives.

Examples of Research Questions	**Comments**
How does bias voltage affect the adhesion and interface structure of Ti-Al-N coatings applied to stainless steel substrates using vacuum arc deposition?	Precise RQ, which probably characterizes the research accurately.
What is the maximum number of cores in a multi-core fiber in which it is possible to write a single identical fiber Bragg grating notch using the phase mask writing method?	Precise RQ, which probably characterizes the research accurately. Presumably the answer is a number.
Can we reduce the cost of an Al-Sc-Er-Zr-Si alloy by adjusting the concentration of both Sc and Zr, while keeping good mechanical properties?	Precise RQ, which demands a yes/no answer. Presumably the answer is yes, since proving no is difficult.
Do non-thermal effects contribute to microwave killing of bacteria and viruses?	Precise RQ, which demands a yes/no answer. Presumably the answer is yes, since proving no is difficult.
Which metal-ceramic brazing method produces the strongest junction between alumina (AL_2O_3) and stainless steel using as brazing filler copper, silver and Ticusil®?	Precise RQ. Expect the answer to be the name or description of the best method.
Are atmospheric pressure plasmas able to rupture the cell wall of microalgae to extract their valuable compounds and can they be an energy efficient, cost saving alternative compared to standard methods?	Two RQs, each demanding a yes/no answer. Both are presumably yes, as no would be difficult to prove.
What is the formation mechanism of micro-discharges in atmospheric pressure CO_2 plasmas?	Precise RQ. Answer will be a description of the mechanism.

Examples of Research Questions	Comments
Will plasma treatment with kINPen MED and plasmaONE harm the surface of human skin by overheating the skin surface, damaging the structure of the stratum corneum, affecting beta-carotene content, or exposing the skin surface to excessive UV radiation?	Precise RQ if the two treatments are rigorously defined. Demands yes/no answer. If the treatments are not rigorously defined, proving "no" may be difficult.
How can the Multanova 6F speed radar be calibrated electronically for the full speed range of 30–249 km/hr?	Precise RQ. Expected answer would be a calibration procedure.
How can the efficiency of a CMOS rectifier be improved for transcutaneously-powered implants?	Precise RQ. Expect the paper will either compare various means of improving the efficiency, or the exposition of some particular means.
How can the dielectric breakdown properties of SF_6 and metal vapor mixtures be calculated in the 300–3000 K temperature range?	Precise RQ, but is it the real RQ? The answer to this RQ is the exposition of a theoretical method. But possibly a better RQ would be: *What are the dielectric breakdown properties of SF_6 and metal vapor mixtures in the 300–3000 K temperature range?* The answer to the latter RQ would be graphs of the breakdown field as a function of T for various mixtures.
Are supermassive black holes formed by the merging of several intermediate-mass black holes?	Was merging the only hypothesis examined? If not, a better alternative might be: *How are supermassive black holes formed?*

2.2.2 *Principal claims*

Many authors find it useful to list the principal claims or principal results of their research as an aid to organizing their paper. These claims or results, taken together, should lead the author and the readers to the principal conclusion of the paper, which is the answer to the research question described in section 2.2.1. Generally, each claim or result will be embodied in a figure or table in the Results section of the paper. This exposition of results forms the core of the paper.

2.2.3 *Outline*

A detailed outline of the research report indicates each section, sub-section, sub-sub-section etc. down to the level of the individual paragraphs (i.e. a separate line entry composed of one or a few words for each paragraph). An example is presented in Table 2.2. Writing a detailed outline is useful in several respects. It guides the writing process by forcing the author to first think about the big issues and not get hung-up on phrasing. And it helps prevent one of the most common problems – misplaced statements (e.g. placing a result of the current research in the Literature Review, or providing a detail of the experimental procedure only after the relevant result is reported).

The outline is recorded as bits and bytes in a word processor, not chiseled in stone. Thus, during the course of the writing it may be revised as the author's ideas become better formulated. Careful consideration of revisions in the context of the outline will help keep the structure logical and avoid add-ons which do not develop the key points.

2.2.4 *Considering the reader*

The overriding consideration in organizing the structure of a research report is to provide information to the reader in the most easily absorbed form. This implies several operative guidelines:

(1) Use conventional organization as outlined in section 2.3. The reader expects it and can absorb the information most readily if the paper is conventionally organized.

(2) Order the paper so that it most efficiently transmits information to the reader. This is not necessarily the order in which the researcher performed the research. The order taken by the researcher is only relevant if it influenced the results, e.g. the sequence of steps in an experimental procedure.