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Review:

A Book for Students of Science and Practicing Scientists: Review of Peter M. Pruzan's 'Research Methodology: The Aims, Practices and Ethics of Science'

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Abstract

This article is a review of a book on research methodology. The book covers a broader range of issues than is usually covered in the training of scientists. It deals with the aims and limitations of science and how one may distinguish between science and other forms of intellectual activity. The book offers elaborate coverage of the process of science, the uncertainties involved in it, and the issues of ethics and integrity. Thus, it delves into areas essential for the practice of science. It equips the reader with the conceptual repertoire and the critical outlook necessary to perform and write about science in a responsible manner. The book is highly recommended for both science students and practicing scientists.

Index Terms: design of research; experimentation and measurement in science; philosophy and practice of science; probability and statistics in science; research ethics; scientific method; training of scientists

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Research Methodology: The Aims, Practices and Ethics of Science. Book by Peter M. Pruzan. Published by Springer International Publishing, Cham, Switzerland, 2016, 326 pages, ISBN-13 978-3-319-271668. Amazon price: Hardcover USD74.62 (as on August 13, 2017).

1. About Author & Reviewer: A Personal Disclosure

Peter M. Pruzan and I sometimes collaborated on our homework as undergraduates in electrical engineering at Princeton University. We graduated together in 1957. After graduation, Peter and I lost track of each other. A few months ago, I came across his name and email address in an alumni publication. I emailed him and we re-established our friendship after 60 years. In the ensuing email exchange, I learned about Peter's book on research methodology, a subject of great interest to me. So I bought the book, and I read it cover to cover (over a 6-week period).

My life path and Peter's have diverged significantly since 1957. Peter earned an MBA from Harvard University, a PhD in operations research from Case Western Reserve University, and an advanced post-doctoral degree in mathematical economics from the University of Copenhagen. From a career beginning in business and operations research, his interests have steadily broadened to include the practice and philosophy of science, its limitations, and its ethical and spiritual aspects. Peter has started and run companies and has taught at four universities. He is presently Emeritus Professor of Systems Science in the Department of Management, Politics, and Philosophy at the Copenhagen Business School.

I, on the other hand, have become more focused on my specific technical interests. I have been studying lightning physics for almost 60 years (and am the author of five books on lightning and almost 300 journal papers). My PhD is in electrical engineering (with a physics minor) from Princeton University. I have trained about 40 graduate students at two universities with time out for a stint in industry (studying lightning) and the co-founding of a company that provides lightning location information.

When I was asked to review *Research Methodology* (Pruzan, 2016), my response was that I have a less than perfect background to do so since I am not an expert in most of the topics in the book. The editors of the *Journal of Research Practice*, nevertheless, had the view that my deficient background was a good thing, since I probably represent the majority of scientists who are narrowly trained to practice science in the formal apprenticeship system, a training that:

> . . . tends to omit more fundamental inquiry as to the nature of science, its history, its presuppositions, its aims, its limitation, its relationship to other approaches to generating and evaluating knowledge, its ethical dimension, and so on. (Pruzan, 2016, p. 4)

So, while I have thought about most of the topics in *Research Methodology* at one time or another, my scientific horizons were nevertheless greatly expanded by the book's organization of philosophical material, the wide-ranging examples, the humor, the keen perception, and the remarkable English. And the book is just plainly interesting from both a philosophical point of view and in its considerable practical material, a breadth of material not found elsewhere. The book was written for PhD students, but it is certainly of considerable value to practicing scientists like me.

2. Subject Matter & Range of Issues Covered

Chapter 1. Introduction

> The following quote from the Introduction gives a good summary of the issues that the author addresses in the book:
>
> What do we really mean by science and scientific knowledge? What are the aims, claims and limitations of science and how can one distinguish between science and other forms of intellectual activity?
>
> Does science have a metaphysical basis?
>
> Is there a "standard" approach to performing research that is widely accepted? In other words, are there general principles or "rules of the game" that one should follow when performing research?
>
> If there are such general principles, are they more or less independent of one's major field of science and of one's culture? Or does each branch of science, perhaps even each specialization within a branch (e.g. quantum mechanics in physics, genetics in biology, artificial life in computer science, palaeontology in geology, polymer organic chemistry in chemistry, galactic astronomy in astronomy) have its own research methodology?
>
> How can I carry out and present my research in such a way that more experienced peers will evaluate it is being "good science" and not "poor science", or even "non-science"?
>
> More specifically, how can and should I choose and justify my choice of hypotheses or research questions? My data collection procedures? My experimental designs? My analyses and conclusions?
>
> How can I provide rational arguments, based on my experiments and observations that will be accepted as having scientific validity?
>
> How can I use probability and statistics to take account of the many uncertainties that characterize research?

> How can I complement my specific and specialized research with an appreciation of the importance and demands of multidisciplinary and interdisciplinary research?
>
> How should I plan my research, including writing my thesis, in such a way that I can complete my research project within the allotted time without having to experience fear and stress?
>
> Is there a particular way that I should write my thesis/article/book? Are there internationally accepted guidelines for structuring scientific publications and are such guidelines independent of one's field of study?
>
> Are there ethical issues I must pay attention to in my research and in my writing? To what extent should such issues and human values influence my research and its mediation?
>
> Does being a scientist imply particular responsibilities to science as a field of inquiry, to the scientific community, and to society in general? (Pruzan, 2016, pp. 2-3)

Chapter 2. Science

The 70-page chapter begins with a 10-page selective history of science followed by a discussion of the various meanings of the word *science*, its limitations, and of pseudo-scientific endeavors. The chapter ends with a very interesting discussion of whether the mathematical models used so successfully in the physical sciences are created by humans or inherent in Nature and simply discovered. This leads to the question of whether it is possible to describe all relationships in the universe with mathematics.

Chapter 3. Hypotheses, Theories and Laws

Often, scientists gloss over the distinctions between the concepts of *hypothesis*, *theory*, and *law*. Apparently, some scientists even treat these as synonyms. The author discusses the definitions and a range of viewpoints on each of these three concepts. The sequence goes from relative uncertainty to relative certainty. A law, the author suggests, is a theory that has been tested extensively, found applicable over a wide range of situations, judged to have low likelihood of being incorrect, is consistent with existing knowledge, and is widely accepted by the scientific community. Interestingly, laws are mainly found in the scientific domains where mathematics is employed, the hard sciences, and less so in the softer sciences where the concept of a law is more like a presupposition.

Chapter 4. Scientific Statements: Their Justification and Acceptance

In order to provide reliable knowledge about physical reality, science needs means and methods for justifying its facts, hypotheses, theories, and laws. This chapter presents a discussion on deductive and inductive reasoning, the refutation of scientific statements, and their acceptance within the scientific community. The chapter ends with a discussion of peer review, the refereeing and evaluation of papers and proposals by the scientific

community, one way that human nature, with its prejudices, values, and ethics, is injected, not always properly, into the process of science. More is found on this subject in Chapter 10.

Chapter 5. Measurement

Introducing the importance and pitfalls of measurement in science, the author states:

> Measurement is thus a fundamental element in science and it is an implicit assumption in the natural sciences that whatever exists in the physical world is potentially subject to direct or indirect observation, and therefore to measurement. (Pruzan, 2016, p. 115)

But, what is the required accuracy of a measurement? This is often determined by how the results of the measurement will be used. The author lists numerous criteria to judge the goodness of a measurement. Measurement errors (all measurements have errors) can result from numerous factors, including the definition of what is actually being measured. Random and systematic errors are discussed, as is the important question of how to treat a measurement value that is outside the expected range. Appendix A considers which quantities are fundamental to a measurement system (e.g., length, time) and which quantities are derived (e.g., speed, acceleration). Appendix B contains a useful discussion on *significant digits* and *rounding*. I have seldom encountered a student with a decent grasp of this issue, particularly since the computer is able to produce endless digits.

Chapter 6. Experimentation

The chapter commences by citing a simple example that illustrates the methodological issues in scientific experimentation. It starts by referring to an observation that grass grows longer among cow pats (i.e., cow dung) in a field than elsewhere in the same field. Three hypotheses are then offered as possible explanations of the additional growth: (1) the additional growth is due to the fertilizing effect of the dung, (2) the additional growth is due to the dung's mulching effect whereby it traps moisture, and (3) the additional growth is due to the disinclination of cows to eat the grass around their own dung.

The author argues that it is not that easy to design an experiment that would provide a more or less conclusive explanation of the observation. In addition to the three hypotheses, there may be other factors that a researcher must consider, the so-called extraneous variables, which may in fact play a role. For example, it may be relevant to consider the type of soil and grass in the field; the number, age, and type of cows; the climatic conditions; and the location of the field (altitude and geography). So deciding which variables to include in one's investigation and how to include them is an important aspect of any experimental design. It will also be necessary to consider measurement aspects: how to measure the rate of growth of grass among the cow pats in order to be able to compare it to the rate of growth of grass where there are no or fewer pats. And of course there is the whole matter of how to design an experiment so that it will be considered valid and reliable, as well as how to analyze the resultant data and draw conclusions. An appendix provides an example of several such considerations in

connection with a very simple and down-to-earth experiment regarding the baking of bread!

The chapter then proceeds to deal with how experiments can contribute to providing "good" answers to research questions. It considers the roles and limitations of experimentation, validity and reliability in experimentation, and the design of experiments, providing examples that can be understood by the general reader, irrespective of disciplinary background. It also considers how research can be carried out without performing experiments, which is typically the case in the social sciences, where active experimentation is rarely used.

Chapter 7. Scientific Method and the Design of Research

What is "the scientific method"? The first half of the chapter considers several answers to that question. Views on the scientific method in the "harder" sciences, such as physics, differ from those in the "softer" sciences, such as sociology. The second half of the chapter offers practical guidelines for structuring one's thoughts on designing a research project. The discussion involves a model for research design. Reference is made to the discussions on justification, verification, falsification, and acceptance presented in Chapter 4 and the discussions on validity and generalization presented in Chapters 5 and 6. Detailed checklists are given for the preparation of research proposals and dissertations.

Chapter 8. Uncertainty, Probability and Statistics in Research

The author is clearly interested in uncertainty and its scientific cousins: probability and statistics. He states that there is often a lack of knowledge about this important aspect of science (that is so true in my case) and this justifies the almost 50-page chapter. The author lays out the importance of understanding uncertainty, especially as the scope of science has expanded from the study of deterministic systems to systems involving random change:

> Although classical systems in physics are in principle deterministic, practical considerations when facing many degrees of freedom may compel the researcher to introduce probability distributions, averages over the distributions, measures of deviations, and so on. And at the quantum level, because of the indeterminacy of dynamical quantities like position and momentum, probability distributions of such variables are inherent to the whole field of study; the laws of physics are statistical, not deterministic. Similarly in biology, it is not possible to discuss evolution, at least within the broadly accepted framework of Darwinism, without including concepts of random change via mutations. (Pruzan, 2016, p. 207)

There is an overview of the chapter at its end, which is worth reading initially. Within the chapter, the use and misuse of probability theory is discussed, followed by a consideration of inductive logic and statistics. The discussions are illustrated by many

examples. I did not find this chapter as easy to read as most of the others, probably because of my insufficient background in probability and statistics.

Chapter 9. Research

To this point in the book, the word *research* has been used repeatedly, but it has not been specifically defined and delimited. The author commences with the following straightforward definition of research in the natural science context:

> Research in the natural sciences is a systematic process for developing new knowledge of the physical world that can be shared and contested. (Pruzan, 2016, p. 257)

This sentence is then dissected as to the meanings of its constituent words. Based on this, inferences are drawn with respect to the following topics: (1) types of research: basic, applied, and evaluation, (2) multidisciplinary and interdisciplinary research, (3) research skills, (4) formulating a research problem, and (5) the relation of research to teaching and publishing.

Chapter 10. Ethics and Responsibility in Scientific Research

Regrettably, my own many years of teaching and research experience indicates that it is seldom that undergraduates or graduate students are formally exposed to the information in Chapter 10 in *Research Methodology* on ethics and responsibility in scientific research. The chapter contains an excellent, thought-provoking discussion on research ethics and a researcher's responsibility, and how these responsibilities are attributed differently in different cultures. Lack of ethics, including harm to sentient beings, harm to the environment, invasion of privacy, lack of informed consent, deception, and coercion, receive considerable attention in this chapter. Detailed discussion is also presented on matters of research integrity such as plagiarism, misuse and fabrication of data, criteria for authorship, self-citation, correction of published errors, duplicate publication, and more. A 2011 publication, *Guidelines for Responsible Conduct of Research* is referenced and quoted (University of Pittsburgh, 2011). The book concludes with a 7-page section containing the author's views on the responsibility of scientists and of science as an institution.

3. Conclusion and Possible Impact on My Own Research Thinking & Practice

In the survey above of the individual chapters, I found it to be very difficult to characterize adequately in limited space the wide range of material in each chapter. So, I have primarily chosen to identify those items that particularly resonate with me while giving some flavor of the material in each chapter.

As viewed from my perspective as a working scientist, *Research Methodology* is a remarkable book which I highly recommend to both PhD students and working scientists. It is clear, well written, and thought provoking. It provided me with ample evidence that

the old saying: “You can’t teach an old dog new tricks” does not always apply to old scientists. Although I do not know just now how I will adapt my scientific practices after reading the book, I can state with certainty that henceforth I will have a keener awareness of some important issues I more or less took for granted in the past. Hopefully, this will enable me to be more reflective in my practice and to be a better mentor for my graduate students—so that they may live up to the very first words a reader of the book meets in the Foreword:

> To perform “good research” in the natural sciences the practitioner must draw upon an inquisitive mind, an appreciation of the methods, aims and limitations of science, and, of course, skill in applying the “tools of the trade”. (Pruzan, 2016, p. v)

References

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