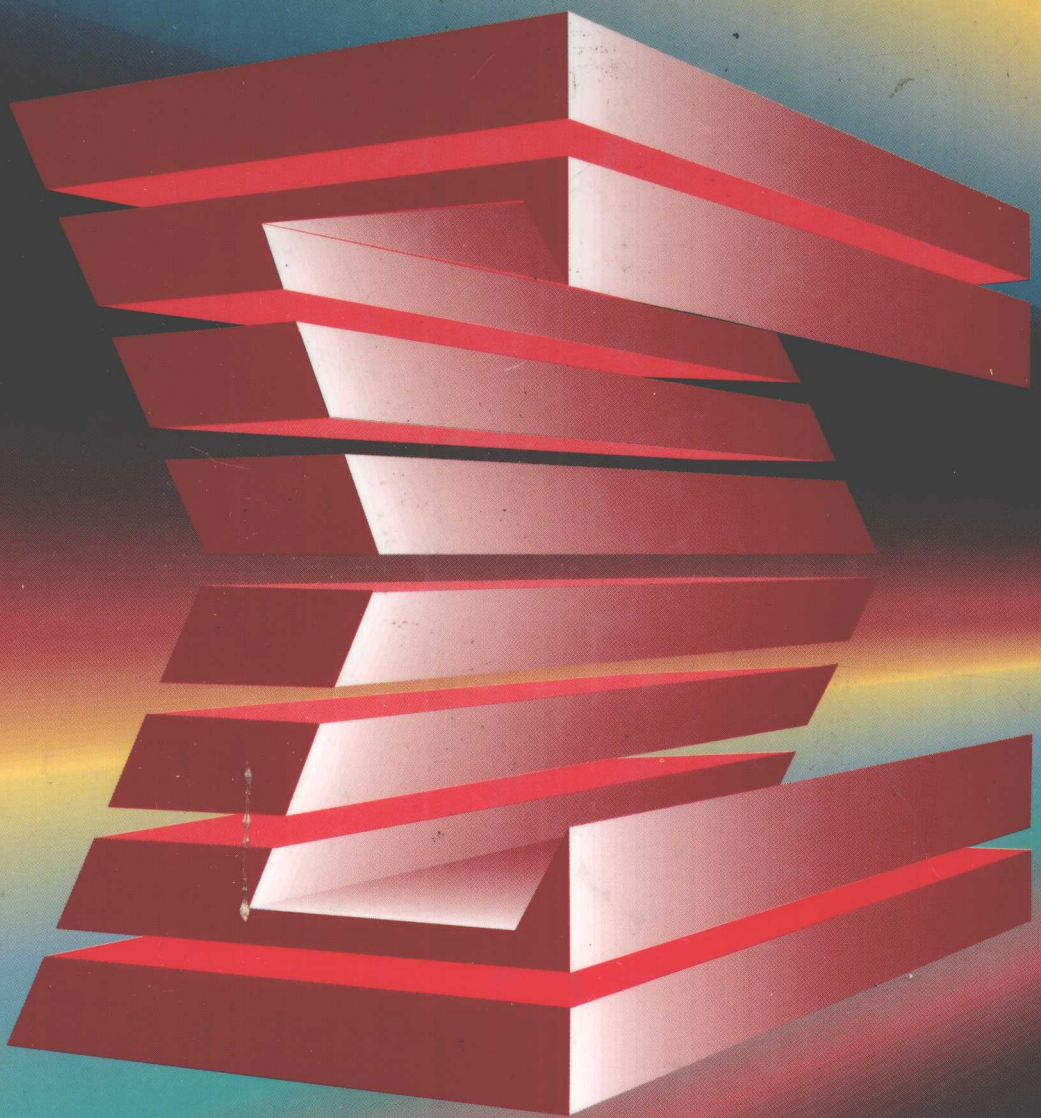
UNDERSTANDING STATISTICS

IN THE BEHAVIORAL SCIENCES

ROBERT R. PAGANO



THIRD EDITION

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PREFACE

I have been teaching a basic introductory statistics course within the Department of Psychology at the University of Washington, for over 15 years. This textbook, first in note form, then as the first two editions, and currently as the third edition, has been the mainstay of the course. Most of my students have been psychology majors, but many have also come from nursing, business, education and other disciplines. Because these students are not well grounded in mathematics, I have used an informal approach, one that assumes only high school algebra as background and one that provides detailed description and many fully solved practice problems. This course is quite successful, with students giving it high ratings. Students rate the textbook even higher, saying among other things that it is very clear and that it helps them a lot to have material presented in such great detail.

Preparing the third edition of this textbook has been very gratifying. It has been so because the feedback from students and professors using the second edition has been quite laudatory. Many say that I shouldn't make too many changes, because the textbook works so well as it is. Nonetheless, there are good reasons for making certain changes. The changes that have been made include (1) expansion of the computer aspects of the text, (2) addition of some exploratory data analysis techniques in Chapter 3, and (3) revision of Chapter 11, Power.

TEXTBOOK RATIONALE

This is an introductory textbook that covers both descriptive and inferential statistics. It is intended for students majoring in the behavioral sciences. For many behavioral sciences undergraduates, statistics is a subject that engenders considerable anxiety and that is avoided for as long as possible. Moreover, I think it is fair to say that when the usual undergraduate statistics course is completed, many students have not understood much of the inferential statistics material. This happens partly because the material is inherently difficult and the students themselves are not proficient in mathematics but also, in my opinion, partly because most textbooks do a poor job of explaining inferential statistics to this group of students. These texts usually err in one or more of the following ways: (1) They are not clearly written; (2) they are not sufficiently detailed, (3) they present the material too mathematically; (4) they present the material at too low a level; (5) they do not give a sufficient number of fully solved problems for the student to practice on; and (6) in inferential statistics, they use an inappropriate sequence of topics, beginning with the sampling distribution of the mean.

In this and the previous two editions, I have tried to correct such deficiencies through an informal writing style; a clearly written, detailed, and theoretically oriented presentation that requires only high school algebra for understanding; the

inclusion of many interesting, fully solved practice problems that are located immediately following the relevant expository material; and a sequencing of the inferential material better suited to the students for whom this book is intended.

I believe a key to understanding inferential statistics is the material presented in the beginning inferential chapters and its sequencing. In my opinion, optimal learning of the material occurs when it is sequenced as follows: random sampling and probability, binomial distribution, introduction to hypothesis testing using the sign test, power, Mann-Whitney *U* test, sampling distributions (including their empirical generation), sampling distribution of the mean, *z* test for single samples, *t* test for single samples, confidence intervals, *t* test for correlated and independent groups, introduction to analysis of variance, multiple comparisons, two-way ANOVA, nonparametric tests, and review of inferential statistics.

At the heart of statistical inference lies the concept of sampling distribution. The first sampling distribution discussed by most texts is sampling distribution of the mean. The difficulty here is that the sampling distribution of the mean cannot be generated from simple probability considerations, which makes it hard to understand. This problem is compounded by the fact that most texts do not attempt to generate the sampling distribution of the mean in a concrete way. Rather, they define it theoretically, as a probability distribution that would result if an infinite number of random samples were taken of size N from the population and the mean of each sample were calculated. This definition is far too abstract for students, especially when this is their initial contact with the idea of sampling distributions. And when students fail to grasp the concept of sampling distributions, they fail to grasp the rest of inferential statistics. What appears to happen is that since students do not understand the material conceptually, they are forced to memorize the equations and to solve problems rotely. Thus, students are often able to solve the problems without genuinely understanding what they are doing —all because they fail to comprehend the essence of sampling distributions.

To impart a basic understanding, I believe it is much better to begin with the sign test (Chapter 10), a simple inference test for which the binomial distribution is the appropriate sampling distribution. The binomial distribution is easy to comprehend, and it can be derived from the basic probability rules developed in an earlier chapter (Chapter 8, Random Sampling and Probability). It depends entirely on logical considerations. Hence, its generation is easily followed. Moreover, it can also be generated by the same empirical process used later on for generating the sampling distribution of the mean. It therefore serves as an important bridge to understanding all the sampling distributions discussed later in the textbook. Introducing hypothesis testing along with the sign test has other advantages: All the important concepts involving hypothesis testing can be illustrated: e.g., null hypothesis, alternative hypothesis, alpha level, and Type I and Type II errors. The sign test also provides an illustration of the before-after (repeated measures) design, which is a superior way to begin, as most students are familiar with this type of experiment, and the logic of the design can be followed with ease.

Chapter 11 discusses power. Many texts either do not discuss power at all or else leave it until near the end of the book. "Power" is a complicated topic. Using the sign test as the vehicle for a power analysis simplifies matters. Understanding power is necessary if one is to grasp the methodology of scientific investigation itself. When students gain insight into power, they can see why we bother discussing Type II errors. Further, they see for the first time why we conclude by "retaining H_0" as a reasonable explanation of the data rather than by "accepting H_0 as true" (a most important distinction). In this same vein, students also appreciate

the error involved when one concludes that two conditions are equal from data that are not statistically significant. Thus, power is a topic that brings the whole hypothesis testing methodology into sharp focus.

Chapter 12 takes up the Mann-Whitney *U* test. This is a practical, powerful test that also has an easily understood sampling distribution. Both the sign test and Mann-Whitney *U* test have sampling distributions derived from basic probability considerations. The Mann-Whitney *U* test is additionally useful in that it illustrates the independent groups design. By the time students finish this chapter, they should have a sound knowledge of hypothesis testing as well as having experienced excellent exposure to the two basic experimental designs. Their confidence in "getting" the fundamentals of statistics should be greatly increased.

Chapter 13 initiates a formal discussion of sampling distributions and how they can be generated. After this, the sampling distribution of the mean is introduced, and *discussion centers on how this sampling distribution can be generated empirically,* which gives students a concrete understanding of the sampling distribution of the mean. With prior experience of the binomial distribution and the sampling distribution of *U*, and with knowledge of the empirical approach for the sampling distribution of the mean, most conscientious students will have achieved a good grasp of why sampling distributions are essential for inferential statistics. Since the sampling distributions underlying student's *t* test and the analysis of variance are also explained in terms of their empirical generation, students can conceptually comprehend the use of these tests rather than just solve problems by rote. This approach gives the insight that *all* the concepts of hypothesis testing are the same as we go from statistic to statistic—what varies from experiment to experiment is the statistic used and its accompanying sampling distribution. The stage is now set for covering the remaining inference tests.

Chapter 13, 14, 15, and 19 discuss, in a fairly conventional way, the *z* test and *t* test for single samples, the *t* test for correlated and independent groups, and nonparametric statistics. However, these chapters differ from those in other texts in their clarity of presentation, the quantity and interest value of the fully solved problems they contain, and the treatment of the relevant sampling distributions. Then, too, there are differences specific to each test. For example: (1) the *t* test for correlated groups is developed as a special case of the *t* test for single samples, this time using difference scores rather than raw scores; (2) the sign test and the *t* test for correlated groups are compared to illustrate the difference in power that results from using one or the other; (3) the factors influencing the power of experiments using student's *t* test are taken up; (4) the correlated and independent groups designs are contrasted with regard to utility.

Chapters 16 and 18 deal with analysis of variance. In these chapters single rather than double subscript notation is deliberately employed. The more complex double subscript notation serves to confuse students. In my view, the single subscript notation and resulting single summations work better for the undergraduate major in psychology and related fields because they are simpler and, for this audience, promote understanding of this reasonably complicated material. Here, I have followed in part the notation used by Edward Minium in *Statistical Reasoning in Psychology and Education.* I am indebted to Professor Minium for this contribution.

Other features of this textbook are worth noting. Chapter 8, on probability, does not delve deeply into probability theory. This is not necessary since the proper mathematical foundation for all the inference tests contained in this textbook can be built as is done in Chapter 8 by the use of basic probability definitions,

the addition rule and the multiplication rule. Chapter 17, covering both planned and *post hoc* comparisons, contains two *post hoc* tests: the Tukey HSD test and the Newman-Kehls test. Chapter 18 is a separate chapter on two-way ANOVA for instructors wishing to cover this topic in depth. For instructors with insufficient time for in-depth handling of two-way ANOVA, at the end of Chapter 16 on one-way ANOVA, I have qualitatively described the two-way ANOVA technique, emphasizing the concept of main effects and interactions. Chapter 20 is a review chapter which brings together all of the inference tests and provides practice in determining which test to use when analyzing data from different experimental designs and data of different levels of scaling. Students especially like the tree diagram on page 444 for helping them determine the appropriate test. Finally, at various places throughout the text, there are sections titled "What is the Truth?" These sections show students practical applications of statistics.

The inferential material in this textbook is intended to be used in the sequence presented. However, if time constrains, Chapter 12 (the Mann-Whitney *U* test) may be omitted without injuring the rest of the material. If desired, Chapter 11, on power, may be skipped and power discussed in conjunction with the normal deviate test in Chapter 13. Alternatively, the instructor could shorten the treatment of power by emphasizing the qualitative rather than quantitative aspects of Chapter 11.

Some comments about the descriptive statistics part of this book: The material is presented at a level that (1) serves as a foundation for the inference chapters and (2) enables students to adequately describe the data for its own sake. For the most part, material on descriptive statistics follows a traditional format because this works well. There are a few exceptions, most notably Chapters 1, 6, and 7. Chapter 1 discusses approaches for determining truth and establishes statistics as part of the scientific method, which is somewhat unusual for a statistics text. Chapters 6 and 7 (on correlation and regression) reverse the conventional order of presentation, treating linear regression first, and correlation second. This has been done because I believe correlation is best understood by using the concepts developed in linear regression.

Finally, I should say something about how I have handled the use of computers. I have written the textbook so that it can be used with or without computers. The computer material contained in the text includes fully computer-solved MINITAB problems placed in appropriate chapters throughout the textbook and separate, end-of-chapter computer exercises for students to do, using MINITAB software. Answers to the computer exercises are provided either in Appendix E or in the *Instructor's Manual.* Appendix A contains a discussion of computers and a detailed description of MINITAB, including the commands necessary for use with the text material. MINITAB has been chosen because it is so easy to learn, is sufficiently complex to handle the material covered in this textbook, and is available on a wide variety of computers, including main frames, minicomputers, and microcomputers. *The computer material can be totally ignored or used at different levels, varying from just having students read selected, fully solved MINITAB problems to having students use MINITAB software to illustrate concepts and solve computer exercises throughout the text.*

THIRD EDITION CHANGES

NEW MATERIAL As mentioned earlier, because of positive feedback from users of the second edition, third edition changes are not major. The changes include:

- Expansion of the computer material. This has been done because student use of computers has greatly increased since the second edition was first published.

The introduction of computers has been moved from Chapter 4 to Chapter 1. The number of fully computer-solved MINITAB problems has been increased from 6 to 15. These problems are contained in Chapters 2, 3, 4, 6, 7, 14, 15, 16, 18, and 19. End-of-chapter computer exercises for these chapters have also been added. Answers to the exercises have been provided either in Appendix E or in the *Instructor's Manual.* In addition, a new appendix, Appendix A, has been included. This appendix contains a rudimentary discussion of computers, and a detailed description of MINITAB, including a discussion of the commands that are useful for the material in this text. It should be emphasized that the computer material has been written such that the instructor can omit it in its entirety or use it in varying degrees, without affecting the text material.

- An added section on exploratory data analysis in Chapter 3. This section emphasizes construction of stem and leaf diagrams.
- Revision of Chapter 11, Power. In particular, a new term P_{null} has been introduced, and a different definition of power is emphasized. This revision helps students gain a better understanding of this difficult topic. It also helps tie together this chapter and the discussion of power in Chapter 13.
- Revision of the section covering the Spearman rank order correlation coefficient in Chapter 7.
- Revision of the section on one- and two-tailed probability evluations in Chapter 10 for greater clarity.
- Increased emphasis in Chapter 4 that the sample standard deviation (s) used in this text is estimated σ.
- Minor wording and formatting changes made throughout the text to increase clarity.

SUPPLEMENTS *The supplements consist of:*

- A **student's study guide,** which is intended for review and consolidation of the material contained in each chapter of the textbook. Each chapter of the study guide has a chapter outline, a programmed learning concept review, exercises and answers to exercises, true-false questions and answers, and an end-of-chapter self-quiz with answers. Many students have commented on the helpfulness of this study guide.
- An **instructor's manual,** which contains short answer, multiple choice and true-false questions for each chapter. The answers to the multiple choice and true-false questions are given in bold type to the left of the question. This manual also contains answers to selected end-of-chapter questions contained in the textbook. Because of requests from instructors, I have not included answers to *all* the computational end-of-chapter questions found in the text; rather, I have omitted answers from a least one question in each chapter. The omitted answers are found near the end of the *Instructor's Manual.* Finally, answers to the computer exercises that were too long to be included in the textbook have been placed at the end of this manual.
- Software: The text uses MINITAB, which is a statistical software program widely available for mainframes, minicomputers, and PCs. It assumes that this software is already on hand or will be supplied by the student, department, or university. A student version is now commercially available.
- Another option: MYSTAT is available with this text. It is an instructional version of SYSTAT, a well-respected and sophisticated statistical package. MYSTAT provides a full-screen data editor, algebraic variable transformations, sorting, ranking, and weighting, descriptive statistics, multi-way tabulations, chi-square, correlation, regression, ANOVA, ANOCOVA, nonparametric

tests, scatterplots, box plots, histograms, stem-and-leaf diagrams and time series plots.

ACKNOWLEDGMENTS

Many people have contributed to this textbook. Foremost is Clyde Perlee, the editor-in-chief of the College Division of West Publishing Company. I am very grateful for his creativity and continuing dedication to producing a fine textbook. This book has also profited greatly from the many perceptive and thorough reviews by qualified professors. Accordingly, I wish to thank the following reviewers for their valuable comments:

FIRST EDITION Thomas V. Brown, University of Dayton; William H. Calhoun, University of Tennessee; Stephen S. Cooper, Glendale Community College, Arizona; Steven D. Falkenberg, Eastern Kentucky University; Patricia E. Gay, Rutgers University; Robert C. Haygood, Arizona State University; Richard J. Harris, University of New Mexico; James P. Kahan, University of Southern California; David Kieras, University of Arizona; James A. McMartin, California State University, Northridge; Henry D. Muse, Morehead State University, Kentucky; J. Robert Newman, California State University, Long Beach; Richard A. Rasor, American River College, California; Thomas W. Reynolds, Edinboro State College, Pennsylvania; William L. Sawrey, California State University, Hayward; Glen Sizemore, Northeastern Oklahoma State University; and Eric F. Ward, Western Illinois State University.

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I am grateful to the Literary Executor of the Late Sir Ronald A. Fisher, F.R.S., to Dr. Frank Yates, F.R.S., and to Longman Group Ltd., London, for permission to reprint Tables III, IV and VII from their book *Statistical Tables for Biological, Agricultural and Medical Research* (6th edition, 1974).

The material covered in this textbook, study guide and *Instructor's Manual* is appropriate for undergraduate students with a major in psychology or related behavioral science discipline. I believe the approach I have followed helps considerably to impart this subject matter with understanding. I am grateful to receive any comments that will improve the quality of these materials.

Robert R. Pagano

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Many of the examples and problems used in this textbook are adapted from actual research. The citations for this research are given below.

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Material for the "What Is the Truth?" sections has been adapted from the following sources:

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What Is the Truth? 2: Advertisement in *Cosmopolitan,* 1983, October, p. 154.

What Is the Truth? 3: Puget Power awaits rate decision (1984, September 25), *Journal American,* Section D, p. 1. Graph reprinted with permission.

What Is the Truth? 4: Equation for success: Good principal = good elementary school (1985, August 23), *Seattle Post-Intelligencer,* Section A, pp. 1, 11.

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What Is the Truth? 7: Advertisement in *Cosmopolitan;* 1983, October, p. 95.

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