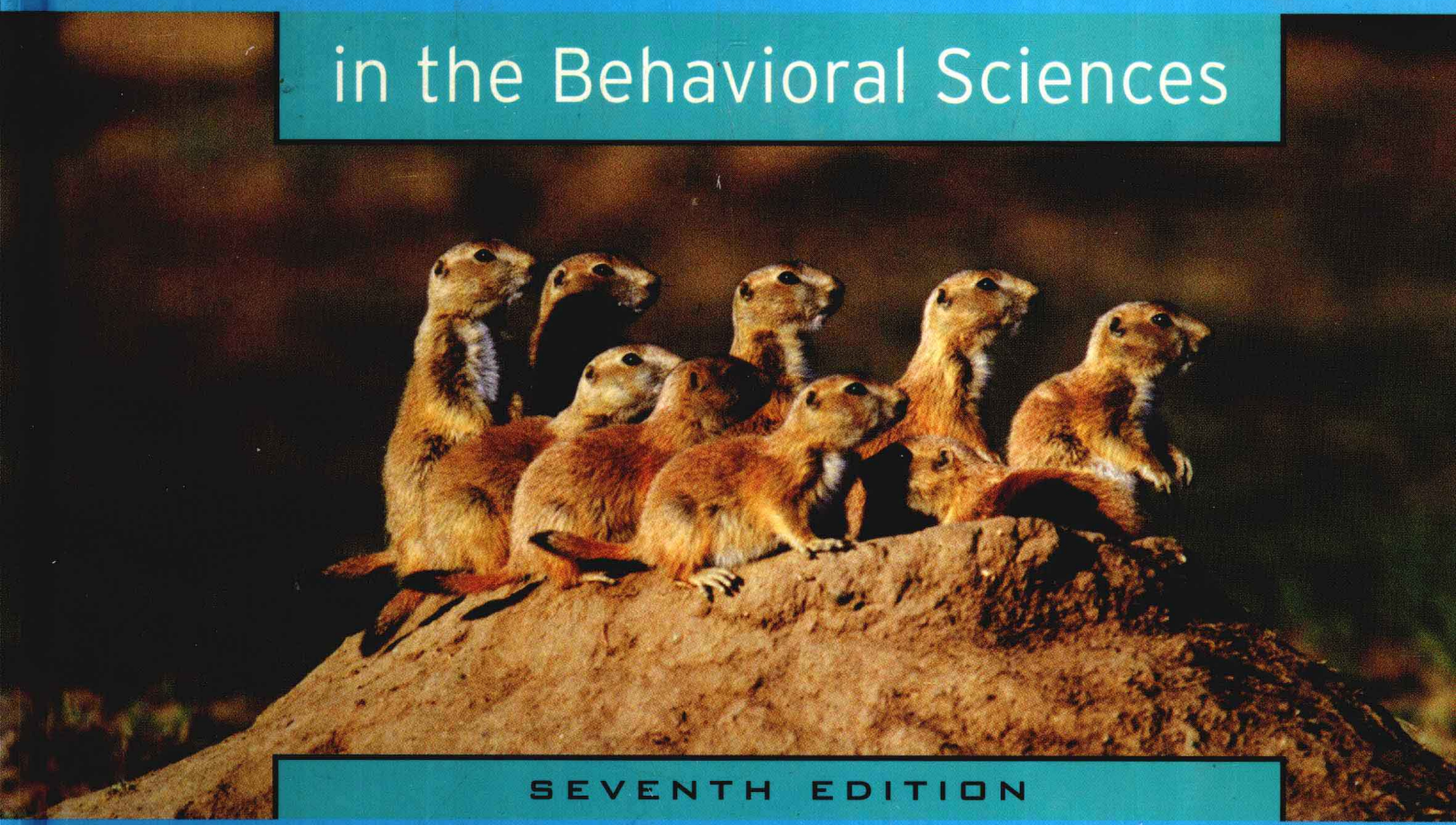
Understanding STATISTICS

in the Behavioral Sciences

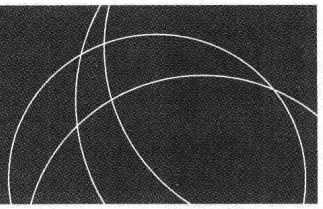


SEVENTH EDITION

Robert R. Pagano

Understanding Statistics in the Behavioral Sciences

EDITION 7



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PREFACE

I have been teaching a course in introductory statistics for more than 30 years, first within the Department of Psychology at the University of Washington, and most recently within the Department of Neuroscience at the University of Pittsburgh. This textbook is the mainstay of the course. Most of my students have been psychology majors, but many have also come from biology, business, education, neuroscience, nursing, and other fields. Because most of these students do not have high aptitude for mathematics and are not well grounded in mathematical skills, I have used an informal rather than strictly mathematical approach. This approach assumes only high school algebra for background knowledge. It relies on clarity of presentation, a particularly effective sequencing of the inferential material, detailed verbal description, interesting illustrative examples, and many fully solved practice problems to help students understand the material.

My statistics course has been quite successful. Students are able to grasp the material, even the more complicated topics like "power," and at the same time, many even enjoy learning it. Student ratings of this course have been quite high. They rate the textbook even higher, saying among other things that it is very clear; they like the touches of humor and state that it helps them to have the material presented in such great detail.

In preparing this seventh edition, I have been guided again by advice and feedback from students and professors. Again, I am very pleased that this feedback has been quite positive and that for most of the textbook the advice has been not to change anything because the text works very well. However, there is one major change, and several more minor changes made in the seventh edition that are worth noting. First, the major change—there is now a free **Companion CD-ROM** that accompanies the textbook. It contains additional fully solved practice problems (approximately two per chapter) for students who would like more guided practice; illustrative examples and practice problems that are solved on the CD using conceptual equations; and chapter-specific computer problem sets that are appropriate for solving using the student edition of SPSS software are included as well. In addition, the CD includes a complete chapter on the Mann–Whitney *U* test. The second change is the addition of a new section in

Chapter 15 titled "Power and the Analysis of Variance." (This is a companion section to the section titled "Power and the *t* Test" in Chapter 14). It extends the discussion of power from the sign test, the *z* test, and the *t* test to the one-way ANOVA. The third change is that in the seventh edition end-of-chapter problems have been color-coded to specify areas within psychology and related fields that the problem is applied. This identification will help instructors assign problems by specific fields and also gives students an appreciation of how broadly statistics applies. Finally, three new "What Is the Truth?" sections have been added: two to Chapter 1 and one to Chapter 10.

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 of these students, statistics is a subject that elicits considerable anxiety and that is avoided for as long as possible. Moreover, I think it is fair to say that when the usual undergraduate course is completed, many students have not understood much of the inferential statistics material. This is partly because the material is inherently difficult and the students themselves are not proficient in mathematics. However, in my opinion, this situation also exists 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 six editions, I have tried to correct such deficiencies by using an informal writing style; using a clearly written, detailed, and theoretically oriented presentation that requires only high school algebra for understanding; including many interesting, fully solved practice problems that are located immediately following the relevant expository material; and using a better sequencing of the inferential material.

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 by using the sign test as the first inference test encountered by the student and by using the following sequence of topics: random sampling and probability, binomial distribution, introduction to hypothesis testing using the sign test, power, 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 finally, a review of all of inferential statistics.

At the heart of statistical inference lies the concept of "sampling distribution." The first sampling distribution discussed by most texts is the sampling distribution of the mean. The problem with this approach is that the sampling distribution of the mean cannot be generated from simple probability considerations, which makes it hard for students 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 sam-

ples of size N were taken 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 the *idea* of sampling distributions. *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 of sampling distributions, I believe it is far 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 very easy to understand, and it can be derived from the basic probability rules developed in an earlier chapter (Chapter 8, "Random Sampling and Probability"). It is entirely dependent on simple, logical considerations. Hence, students can easily follow its generation. Moreover, it can also be generated by the same empirical process that is used later in the text 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 with the sign test has other advantages. All of the important concepts involving hypothesis testing can be illustrated; for example, null hypothesis, alternative hypothesis, alpha level, Type I and Type II errors, size of effect, and power. 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 is quite easy to follow.

Chapter 11 discusses power. Many texts do not discuss power at all or, if they do, 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. Furthermore, 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.

At this state of the exposition, a diligent student can grasp the idea that data analysis basically involves two steps: (1) calculating the appropriate statistic and (2) evaluating the statistic based on its sampling distribution. The time is ripe for a formal discussion of sampling distributions and how they can be generated (Chapter 12). After this, the sampling distribution of the mean is introduced. Rather than depending on an abstract theoretical definition of the sampling distribution of the mean, the text discusses how this sampling distribution can be generated empirically. This gives a much more concrete understanding of the sampling distribution of the mean.

Due to previous experience with one easily understood sampling distribution, the binomial distribution, and using the empirical approach for the sampling distribution of the mean, most conscientious students have a good grasp of what sampling distributions are and why they 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 understand the use of these tests rather than just rotely solving problems. With this background, students can comprehend that all of 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 set for moving through the remaining inference tests.

Chapters 12, 13, 14, and 18 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 textbooks in the clarity of presentation, the number and interest value of fully solved problems, and the use of empirically derived sampling distributions. In addition, there are differences that are specific to each test. For example, (1) the t test for correlated groups is introduced directly after the t test for single samples and is developed as a special case of the t test for single samples, only 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) there is a discussion of the factors influencing the power of experiments using Student's t test; and (4) the correlated and independent groups designs are compared with regard to utility.

Chapters 15 and 17 deal with the analysis of variance. In these chapters, single rather than double subscript notation is deliberately used. 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, they promote understanding of this reasonably complicated material. In using single subscript notation I have followed in part the notation used by E. Minium, *Statistical Reasoning in Psychology and Education*, 2nd edition, John Wiley & Sons, New York, 1978. 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 because the proper mathematical foundation for all of the inference tests contained in this textbook can be built by the use of basic probability definitions, in conjunction with the addition and multiplication rules, as has been done in Chapter 8. Chapter 16, covering both planned and *post hoc* comparisons, contains two *post hoc* tests, the Tukey HSD test and the Newman–Keuls test. Chapter 17 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 beginning of Chapter 17, I have qualitatively described the two-way ANOVA technique, emphasizing the concepts of main effects and interactions. Chapter 19 is a review chapter that 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 in this chapter 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.

Some comments about the descriptive statistics part of this book are in order. The descriptive material is written 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. Chapter 1 is an exception. It dis-

cusses approaches for determining truth and establishes statistics as part of scientific method, which is rather unusual for a statistics textbook.

Seventh Edition Changes

New Material As mentioned earlier, because of positive feedback from users of the sixth edition, seventh edition changes are not extensive. However, there is one major change, as well as many additional more minor ones. These changes include:

- **A New, Free Companion CD-ROM.** This CD-ROM is integrated with the textbook. It contains additional fully solved practice problems (approximately two per chapter) for students who would like more guided practice. Illustrative examples and practice problems that are solved in the textbook using computational equations are also included on the CD. However, these problems are solved on the CD using conceptual instead of computational equations; they will be useful for students in classes taught by professors who prefer their students to work many problems using conceptual equations instead of, or in addition to, computational ones. The last set of problems contained on the CD are chapter-specific computer problem sets that are appropriate for solving using the student edition of SPSS software. These will be quite useful in classes that include an SPSS computer component. Finally, the CD includes a complete chapter on the Mann–Whitney *U* test for use in classes taught by professors who prefer an in depth treatment of this test to the abbreviated treatment given in Chapter 18 of the textbook.
- **Color-Coding of End-of-Chapter Problems.** End-of-chapter problems have been color-coded to identify eight areas in psychology and related fields (cognitive psychology, social psychology, developmental psychology, biological psychology, clinical psychology, industrial/organizational psychology, health psychology, education, and other). This coding should be useful in working problems by area and in helping students appreciate the broad application of statistics.
- **A New Section Titled, "Power and the Analysis of Variance" (in Chapter 15).** This section is a parallel section to "Power of the *t* Test" (in Chapter 14). It extends the coverage of power from the sign test, *z* test, and *t* test to one-way, independent groups ANOVA.
- **New or Revised End-of Chapter Questions and Problems.** More than 30 new or revised end-of-chapter questions and problems have been added to extend and update this material.
- **Qualitative Presentation of Two-Way ANOVA Moved to Chapter 17.** To unify the presentation of two-way ANOVA, the qualitative presentation of two-way ANOVA has been moved from the end of the one-way ANOVA chapter to the beginning of Chapter 17, "Introduction to Two-Way Analysis of Variance."
- **Three New "What Is The Truth?" sections.** Two new, "What Is The Truth?" sections have been added to Chapter 1, and a third new "What Is The Truth?" section has been added to Chapter 10. They are titled, "Data, Data, What Are the Data?—1," "Data, Data, What Are the Data?—2" and "Chance or Real Effect?—2," respectively. The first new section illustrates the point that even though data are presented in a study, the conclusion of the study needs to be appropriate to the data. The second new section also involves data. However, this time the focus is not on, "Are there any data?"

or "Are the data adequate for the truth claims made?" but rather on "How accurate are the data"? The last new section illustrates the point that just because a result is statistically significant, it does not automatically mean that the result is a real effect. In this example, even though statistically significant, the result seems best explained on the basis of chance.

- **Wording and Formatting Changes.** Minor wording and formatting changes have been made throughout the textbook to improve clarity and interest.

Ancillary Package The supplements consist of:

- A **student's study guide** that 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. (0-534-61768-9)
- An **instructor's manual with test bank** that contains teaching advice, chapter outlines for the textbook material, test questions for each chapter, and answers to selected end-of-chapter problems contained in the textbook. The test questions for each chapter are short answer, multiple-choice, and true/false questions. The answers to the multiple-choice and true/false questions are given in bold type to the left of the question. Because of requests from instructors, I have not included answers to *all* the computational end-of-chapter problems found in the text; instead, I have omitted answers from at least one problem in each chapter. These answers are found at the end of the instructor's manual. (0-534-61769-7)
- A free **CD-ROM** that is integrated with the textbook. It contains additional fully solved practice problems (approximately two per chapter) for students who would like more guided practice. Illustrative examples and practice problems that are solved in the textbook using computational equations are also included on the CD. However, these problems are solved on the CD using conceptual instead of computational equations; they will be useful for students in classes taught by professors who prefer their students to work many problems using conceptual equations instead of, or in addition to, computational ones. The last set of problems contained on the CD are chapter-specific computer problem sets that are appropriate for solving using the student edition of SPSS software. These will be quite useful in classes that include an SPSS computer component. Finally, the CD includes a complete chapter on the Mann–Whitney *U* test for use in classes taught by professors who prefer an in-depth treatment of this test to the abbreviated treatment given in Chapter 18 of the textbook. (0-534-61773-5)
- **Software:** The CD-ROM contains computer problems appropriate for solution with the student version of SPSS. I recommend "A Simple Guide to SPSS for Windows, Version 11.0," by Kirkpatrick and Feeny, to asssist the student in navigating through SPSS. It comes with or without the Student Software disk. The manual is available from Wadsworth, alone (0-534-61004-8) or bundled with a disk containing the student version of SPSS. (0-534-04875-7)
- **ExamView,** a computerized testing package for Windows or Macintosh computers that allows instructors to create, edit, store, and print exams. (0-534-61771-9)

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The material covered in this textbook, CD-ROM, 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

BRIEF CONTENTS

CONTENTS