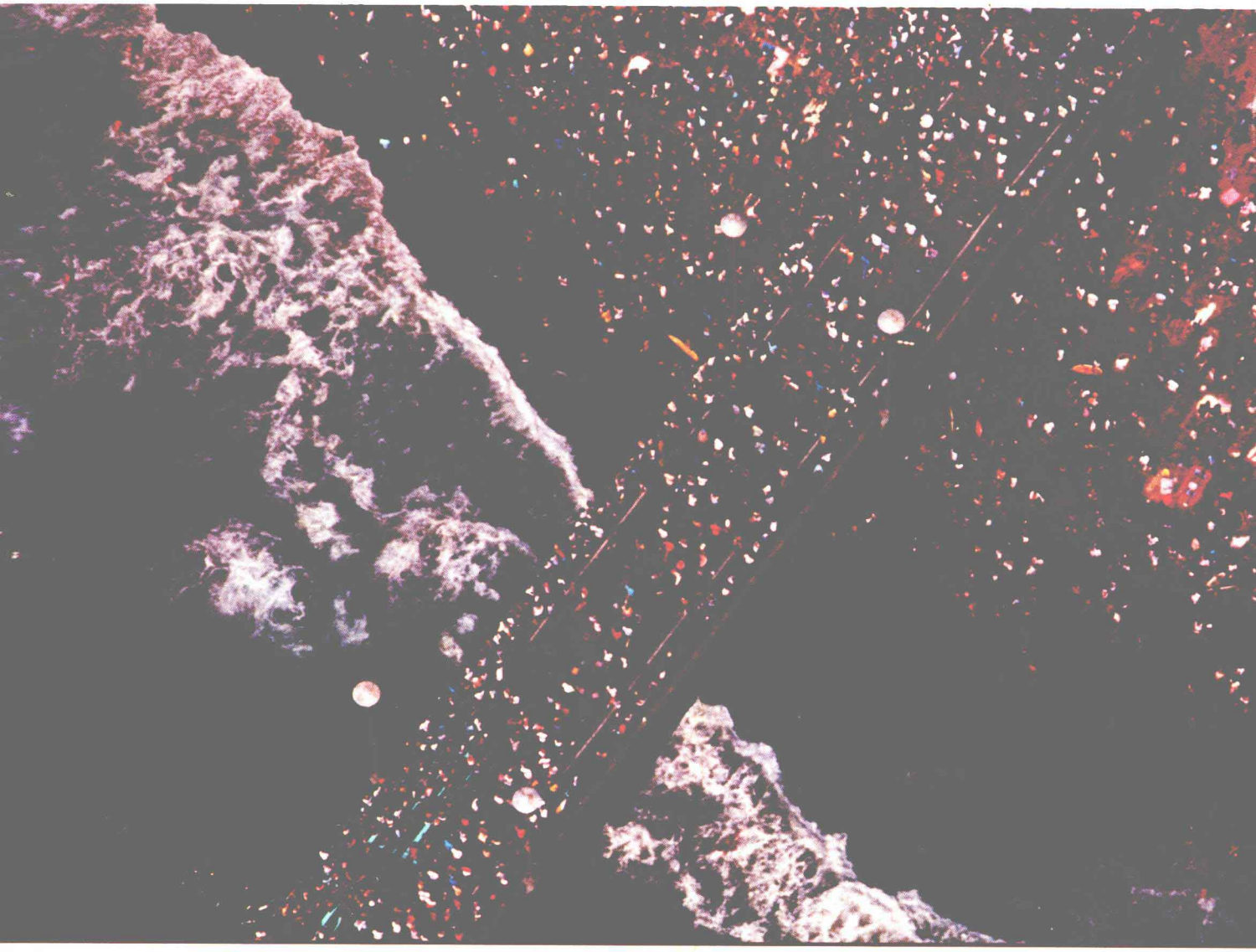
INTRODUCTION TO

Statistics and Data Analysis

Second Edition



Peck Olsen Devore

DUXBURY

Introduction to Statistics and Data Analysis

Second Edition

Roxy Peck
California Polytechnic State University
San Luis Obispo

Chris Olsen
George Washington High School
Cedar Rapids, IA

Jay Devore
California Polytechnic State University
San Luis Obispo

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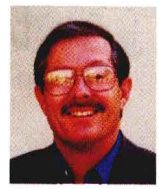
- To my nephews, Jesse and Luke Smidt,
  who bet I wouldn't put their names in this book.
  R. P.
- To my wife, Sally, and my daughter, Anna.
  C. O.
- To Carol, Allie, and Teri.
  J. D.

About the Authors

ROXY PECK is Associate Dean of the College of Science and Mathematics and Professor of Statistics at California Polytechnic State University, San Luis Obispo. Roxy has been on the faculty at Cal Poly since 1979, serving for six years as Chair of the Statistics Department before becoming Associate Dean. She received an M.S. in Mathematics and a Ph.D. in Applied Statistics from the University of California, Riverside. Roxy is nationally known in the area of statistics education, and in 2003 she received the American Statistical Association's Founder's Award, recognizing her contributions to K–12 and undergraduate statistics education. She is a Fellow of the American Statistical Association and an elected member of the International Statistics Institute. Roxy has recently completed five years as the Chief Reader for the Advanced Placement Statistics Exam and currently chairs the American Statistical Association's Joint Committee with the National Council of Teachers of Mathematics on Curriculum in Statistics and Probability for Grades K–12. In addition to her texts in introductory statistics, Roxy is also coeditor of *Statistical Case Studies: A Collaboration Between Academe and Industry* and a member of the editorial board for *Statistics: A Guide to the Unknown*, 4th edition. Outside the classroom and the office, Roxy likes to travel and spends her spare time reading mystery novels. She also collects Navajo rugs and heads to New Mexico whenever she can find the time.

CHRIS OLSEN has taught statistics at George Washington High School in Cedar Rapids, Iowa, for over 25 years. Chris is a past member of the Advanced Placement Statistics Test Development Committee and the author of the *Teacher's Guide for Advanced Placement Statistics*. He has been a table leader at the AP Statistics reading for 6 years and since the summer of 1996 has been a consultant to the College Board. Chris leads workshops and institutes for AP Statistics teachers in the United States and internationally. Chris was the Iowa recipient of the Presidential Award for Excellence in Science and Mathematics Teaching in 1986. He was a regional winner of the IBM Computer Teacher of the Year award in 1988 and received the Siemens Award for Advanced Placement in mathematics in 1999. Chris is a frequent contributor to the AP Statistics Electronic Discussion Group and has reviewed materials for *The Mathematics Teacher*, the AP Central web site, *The American Statistician*, and the *Journal of the American Statistical Association*. He currently writes a column for *Stats* magazine. Chris graduated from Iowa State University with a major in mathematics and, while acquiring graduate degrees at the University of Iowa, concentrated on statistics, computer programming, psychometrics, and test development. Currently, he divides his duties between teaching and evaluation; in addition to teaching, he is the assessment facilitator for the Cedar Rapids, Iowa, Community Schools. In his spare time he enjoys reading and hiking. He and his wife have a daughter, Anna, who is a graduate student in Civil Engineering at Cal Tech.



JAY DEVORE earned his undergraduate degree in Engineering Science from the University of California at Berkeley, spent a year at the University of Sheffield in England, and finished his Ph.D. in statistics at Stanford University. He previously taught at the University of Florida and at Oberlin College and has had visiting appointments at Stanford, Harvard, the University of Washington, and New York University. Jay is currently Professor and Chair of the Statistics Department at California Polytechnic State University, San Luis Obispo. The Statistics Department at Cal Poly has an international reputation for activities in statistics education. In addition to this book, Jay has written several widely used engineering statistics texts and is currently working on a book in applied mathematical statistics. He is the recipient of a distinguished teaching award from Cal Poly and is a Fellow of the American Statistical Association. In his spare time, he enjoys reading, cooking and eating good food, tennis, and travel to faraway places. He is especially proud of his wife, Carol, a retired elementary school teacher, his daughter Allison, who works for the Center for Women and Excellence in Boston, and his daughter Teri, who is finishing a graduate program in education at NYU.

Preface

Introduction to Statistics and Data Analysis, 2nd edition, is intended for use as a textbook for introductory statistics courses at two- and four-year colleges and universities as well as for the Advanced Placement Statistics course, as presented in the Advanced Placement course description. We believe that the following special features of our book distinguish it from other texts.

Features

A Traditional Structure with a Modern Flavor

The topics included in almost all introductory texts are here also. However, we have interwoven new strands that reflect current and important developments in statistical analysis. These include coverage of sampling and experimental design, the role of graphical displays as an important component of data analysis, transformations, residual analysis, normal probability plots, and simulation. The organization gives instructors considerable flexibility in deciding which of these topics to include in a course.

A Focus on Data Analysis

Students are introduced early to the idea that data analysis is a process that begins with careful planning, followed by data collection, data description using graphical and numerical summaries, data analysis, and, finally, interpretation of results. Section 2.1 describes this process in detail, and the ordering of topics in the first 10 chapters of the book is chosen to mirror this process: data collection, then data description, then statistical inference.

The Use of Real Data and the Importance of Context

Many students are skeptical of the relevance and importance of statistics. Contrived problem situations and artificial data often reinforce this skepticism. A strategy that

we have used successfully to motivate students is to present examples and exercises that involve real data extracted from journal articles, newspapers, and other published sources. Most examples and exercises in the book are of this nature; they cover a wide range of disciplines and subject areas, including but not limited to health and fitness, consumer research, psychology and aging, environmental research, law and criminal justice, and entertainment.

Statistics is not about numbers; it is about data — numbers in context. It is the context that makes a problem meaningful and something worth considering. Examples and exercises with overly simple settings do not allow students to practice interpreting results in authentic situations, nor do they give students the experience necessary to be able to use statistical methods in real settings. We believe that the exercises and examples are a particular strength of this text, and we invite you to compare the examples and exercises with those in other introductory statistics texts.

■ Mathematical Level and Notational Simplicity

A good background in second-year algebra constitutes sufficient mathematical preparation for reading and understanding the material presented in this book. We want students to focus on concepts without having to grapple unnecessarily with the manipulation of formulas and symbols.

Table 5.6 ■ Power Transformation Ladder

Power	Transformed Value	Name
3	(Original value)^3	Cube
2	(Original value)^2	Square
1	(Original value)	No transformation
$\frac{1}{2}$	$\sqrt{\text{Original value}}$	Square root
$\frac{1}{3}$	$\sqrt[3]{\text{Original value}}$	Cube root
0	Log(Original value)	Logarithm
-1	$\frac{1}{\text{Original value}}$	Reciprocal

Figure 5.31 is designed to suggest where on the ladder we should go to find an appropriate transformation. The four curved segments, labeled 1, 2, 3, and 4, represent shapes of curved scatterplots that are commonly encountered. Suppose that a scatterplot looks like the curve labeled 1. Then, to straighten the plot, we should use a power of x that is up the ladder from the no-transformation row (x^2 or x^3) and/or a power on y that is also up the ladder from the power 1. Thus, we might be led to squaring each x value, cubing each y, and plotting the transformed pairs. If the cur-

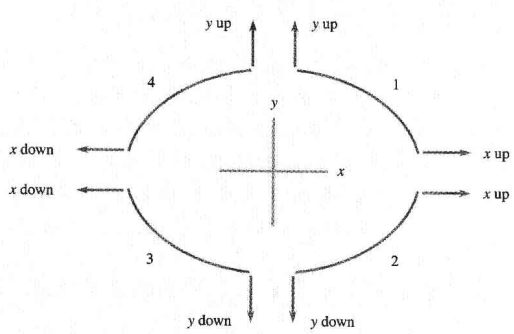


Figure 5.31 Scatterplot shapes and where to go on the transformation ladder to straighten the plot.

■ **One-Sample *t* Test for a Population Mean**

Null hypothesis: H_0: μ = hypothesized value.

Test statistic: $t = \dfrac{\bar{x} - \text{hypothesized value}}{\dfrac{s}{\sqrt{n}}}$

Alternative Hypothesis:	***P*-Value:**
H_a: $\mu >$ hypothesized value	Area to right of calculated t under t curve with df $= n - 1$
H_a: $\mu <$ hypothesized value	Area to the left of calculated t under t curve with df $= n - 1$
H_a: $\mu \neq$ hypothesized value	(1) 2(area to right of t) if t is positive, or (2) 2(area to left of t) if t is negative

Assumptions: 1. $\bar{x}$ and s are the sample mean and sample standard deviation, respectively, from a *random sample.*
2. The *sample size is large* (generally $n \geq 30$) or *the population distribution is at least approximately normal.*

To achieve this, we have sometimes used words and phrases in addition to and in place of symbols. For those who are apprehensive about their mathematical skills, we trust that the verbal descriptions not only are faithful to the statistical concepts but also are stepping stones to the more precise mathematical descriptions.

■ The Use of Technology

The computer has brought incredible statistical power to the desktop of every investigator. The wide availability of statistical computer packages (such as MINITAB, S-Plus, JMP, and SPSS) and the graphical capabilities of the modern microcomputer have transformed both the teaching and learning of statistics. To highlight the role of the computer in contemporary statistics, we have included sample outputs throughout the book.

Figure 5.11 Partial MINITAB output for Example 5.7.

The regression equation is
Return to Sport = − 5.05 + 0.272 Age ← *Equation ŷ = a + bx*

Predictor	Coef	SE Coef	T	P
Constant	−5.054	4.355	−1.16	0.279
Age	0.2715	0.1427	1.90	0.094

Value of a (−5.054) *Value of b* (0.2715)

Most statistical computer packages and graphing calculators can calculate and report *P*-values for a variety of hypothesis-testing situations, including the large-sample test for a proportion. MINITAB was used to carry out the test of Example 10.10, and the resulting computer output follows (MINITAB uses p instead of π to denote the population proportion):

Test and Confidence Interval for One Proportion

Test of p = 0.5 vs p < 0.5

Sample	X	N	Sample p	95.0 % CI	Z-Value	P-Value
1	220	500	0.440000	(0.396491, 0.483509)	−2.68	0.004

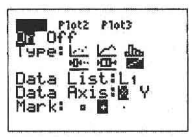
From the MINITAB output, $z = -2.68$, and the associated *P*-value is .004. The small difference in the *P*-value is the result of rounding.

In addition, numerous exercises contain data that can easily be analyzed by computer, although our exposition firmly avoids a presupposition that students have access to a particular statistical package.

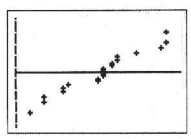
The recent appearance of hand-held calculators with significant statistical and graphing capability has also changed statistics instruction in classrooms where access to computers is still limited. The computer revolution of a previous generation is now being writ small — or, possibly we should say, small*er* — for the youngest generation of investigators. There is not, as we write, anything approaching universal or even wide agreement about the proper role for the calculator in college statistics classes, where access to a computer is more common. At the same time, to tens of thousands of students in Advanced Placement Statistics courses in our high schools, the calculator is the only dependable access to statistical technology.

This text allows either approach and presents the power of the calculator in a series of Graphing Calculator Explorations. These are placed at the end of each chapter, unobtrusive to those instructors whose technology preference runs to computer packages while accessible to those instructors and students comfortable with this technology.

▪ Exploration 9.2: Confidence Interval for a Population Mean



(a)



(b)

Figure 9.12 (a) Edit window for normal probability plot; (b) normal probability plot.

Finding the confidence interval for a single mean on your calculator requires you to navigate the menu system much as you did to find the confidence interval for a proportion. The confidence interval for the mean has some added challenges, however:

1. You need to decide whether to base the interval on the z or the t distribution, and
2. You may use previous calculations of the sample mean and standard deviation, or the calculator will evaluate these statistics from data contained in a List.

We follow Example 9.9, and use the t distribution for our confidence interval. We have entered the data in List1 and are ready to proceed. Because we have chosen to use the t confidence interval, the normality of the population becomes an issue. The original data are at hand, so we can assess the plausibility of a normal population by constructing a normal probability plot. Figure 9.12 shows the resulting normal probability plot.

After verifying the plausibility of the normality of the population, we can now construct the confidence interval. In this case, we have a choice of entering the sample calculations or letting the calculator evaluate the sample mean and standard deviation. Based on that choice, we see one of the screens shown in Figure 9.13.

Figure 9.14 shows one calculator's version of the confidence interval. Once again, we caution you that the calculator only calculates — you must still do the thinking and present the solution in the context of the particular problem at hand.

As with computer packages, our exposition firmly avoids pointing to a particular calculator and presents the calculator capabilities in a generic format; specifically, we do not teach particular keystroke sequences, believing that the best source for such specific information is the calculator manual. As much as possible, the calculator explorations are independent of each other, allowing instructors to pick and choose calculator topics that are more relevant to their particular courses.

▪ Advanced Placement Statistics

We have designed this book with a particular eye toward the syllabus of the Advanced Placement Statistics course and the needs of high school teachers and students. Concerns expressed and questions asked in teacher workshops and on the

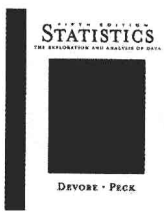
AP Statistics Electronic Discussion Group have strongly influenced our exposition of certain topics, especially in the area of experimental design and probability. We have taken great care to provide precise definitions and clear examples of concepts that Advanced Placement Statistics instructors have acknowledged as difficult for their students. We have also expanded the variety of examples and exercises, recognizing the diverse potential futures envisioned by very capable students who have not yet focused on a college major.

▪ Topic Coverage

Our book can be used in courses as short as one quarter or as long as one year. Particularly in shorter courses, an instructor will need to be selective in deciding which topics to include and which to set aside. The book divides naturally into four major sections: collecting data and descriptive methods (Chapters 1–5), probability material (Chapters 6–8), the basic one- and two-sample inferential techniques (Chapters 9–12), and more advanced inferential methods (Chapters 13–15). We include an early chapter (Chapter 5) on descriptive methods for bivariate numerical data. This early exposure raises questions and issues that should stimulate student interest in the subject; it is also advantageous for those teaching courses in which time constraints preclude covering advanced inferential material. However, this chapter can easily be postponed until the basics of inference have been covered and then combined with Chapter 13 for a unified treatment of regression and correlation.

With the possible exception of Chapter 5, Chapters 1–10 should be covered in order. We anticipate that most instructors will then continue with two-sample inference (Chapter 11) and methods for categorical data analysis (Chapter 12), although regression could be covered before either of these. Analysis of variance (Chapter 15) could be included before or after the regression material of Chapters 13 and 14.

▪ A Note on Probability



The content of the probability chapters is consistent with the Advanced Placement Statistics course description. It includes both a traditional treatment of probability and probability distributions at an introductory level as well as a section on the use of simulation as a tool for estimating probabilities. For those who prefer a briefer and more informal treatment of probability, the book *Statistics: The Exploration and Analysis of Data*, 5th edition, by Jay Devore and Roxy Peck (also published by Duxbury) may be a more appropriate choice. Except for the treatment of probability and the omission of the Graphing Calculator Explorations, it parallels the material in this text.

▪ New in This Edition

There are a number of changes in the 2nd edition, including the following:

- Hands-on activities have been added at the end of each chapter. These activities can be used as a chapter capstone or can be integrated into the text material of the chapter.

- **Activity 8.1: Do Students Who Take the SATs Multiple Times Have an Advantage in College Admissions?**

Technology activity: Requires use of a computer or a graphing calculator.

Background: The *Chronicle of Higher Education* (January 29, 2003) summarized an article that appeared on the *American Prospect* web site titled "College Try: Why Universities Should Stop Encouraging Applicants to Take the SAT's Over and Over Again." This paper argued that current college admission policies that permit applicants to take the SAT exam multiple times and then use the highest score for admission consideration favor students from families with higher incomes (who can afford to take the exam many times). The author proposed two alternatives that he believes would be fairer than using the highest score: (1) Use the average of all test scores, or (2) use only the most recent score.

In this activity, you will investigate the differences between the three possibilities by looking at the sampling distributions of three statistics for a test taker who takes the exam twice and for a test taker who takes the exam five times.

- The final section of most chapters is now titled "Communicating and Interpreting the Results of Statistical Analyses."

For effective communication with graphical displays, some things to remember are:

- Be sure to select a display that is appropriate for the given type of data.
- Be sure to include scales and labels on the axes of graphical displays.
- In comparative plots, be sure to include labels or a legend so that it is clear which parts of the display correspond to which samples or groups in the data set.
- Although it is sometimes a good idea to have axes that don't cross at (0, 0) in a scatterplot, the vertical axis in a bar chart or a histogram should always start at 0 (see the cautions and limitations later in this section for more about this).
- Keep your graphs simple. A simple graphical display is much more effective than one that has a lot of extra "junk." Most people will not spend a great deal of time studying a graphical display, so its message should be clear and straightforward.
- Keep your graphical displays honest. People tend to look quickly at graphical displays, and so it is important that a graph's first impression is an accurate and honest portrayal of the data distribution. In addition to the graphical display itself, data analysis reports usually include a brief discussion of the features of the data distribution based on the graphical display.
- For categorical data, this discussion might be a few sentences on the relative proportion for each category, possibly pointing out categories that were either common or rare compared to other categories.
- For numerical data sets, the discussion of the graphical display usually summarizes the information that the display provides on three characteristics of the data distribution: center or location, spread, and shape.
- For bivariate numerical data, the discussion of the scatterplot would typically focus on the nature of the relationship between the two variables used to construct the plot.
- For data collected over time, any trends or patterns in the time-series plot would be described.

In addition to considering how to interpret statistical summaries found in journals and other published sources, these final sections have been expanded to include advice on how to best communicate results. Also new is a subsection titled "A Word to the Wise: Cautions and Limitations," which reminds readers of things that must be considered to ensure that statistical methods are used in reasonable and appropriate ways.

■ **A Word to the Wise: Cautions and Limitations**

There are several things you should watch for when conducting a hypothesis test or when evaluating a written summary of such a test.

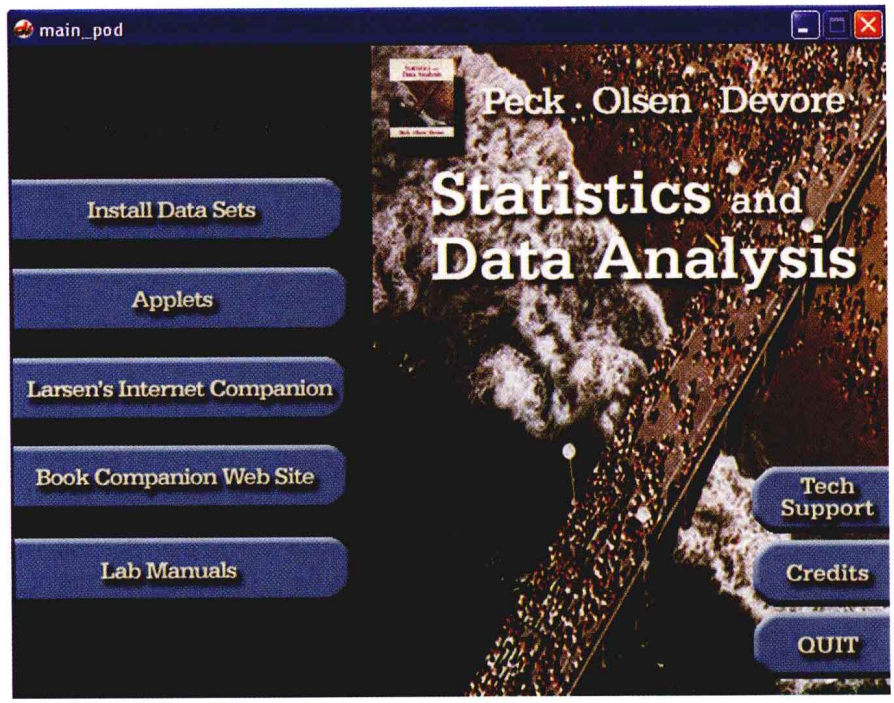
1. The result of a hypothesis test can never show strong support for the null hypothesis. Make sure that you don't confuse "There is no reason to believe the null hypothesis is not true" with the statement "There is convincing evidence that the null hypothesis is true." These are very different statements!
2. If you have complete information for the population, don't carry out a hypothesis test! It should be obvious that no test is needed to answer questions about a population if you have complete information and don't need to generalize from a sample, but people sometimes forget this fact. For example, in an article on growth in the number of prisoners by state, the *San Luis Obispo Tribune* (August 13, 2001) reported "California's numbers showed a statistically insignificant change, with 66 fewer prisoners at the end of 2000." The use of the term "statistically insignificant" implies some sort of statistical inference, which is not appropriate when a complete accounting of the entire prison population is known. Perhaps the author confused statistical and practical significance. Which brings us to . . .
3. Don't confuse statistical significance with practical significance. When statistical significance has been declared, be sure to step back and evaluate the result in light of its practical importance. For example, we may be convinced that the proportion who respond favorably to a proposed medical treatment is greater than .4, the known proportion who respond favorably for the currently recommended treatments. But if our estimate of this proportion for the proposed treatment is .405, is this of any practical interest? It might be if the proposed treatment is less costly or has fewer side effects, but in other cases it may not be of any real interest. Results must always be interpreted in context.

- Coverage of experimental design and survey sampling has been expanded, and two new sections have been added to Chapter 2. Section 2.5 ("More on Experimental Design") discusses the use of a control group, the role of a placebo treatment, single-blind and double-blind experiments, and the use of volunteers as subjects in an experiment. Section 2.6 ("More on Observational Studies: Designing Surveys") addresses the challenges of planning a survey. In addition, Section 2.3 ("Statistical Studies: Observation and Experimentation") has been expanded to include a more complete discussion of the types of conclusions that can reasonably be drawn from statistical studies.
- Although the order of topics generally mirrors the data collection process with methods of data collection covered first, two graphical displays (dotplots and bar charts) have been moved to Chapter 1 so that these simple graphical analysis tools can be used in the conceptual development of experimental design and so that students have some tools for summarizing the data they collect through sampling and experimentation in the exercises, examples, and activities of Chapter 2.
- The coverage of scatterplots has been moved to Chapter 3, "Graphical Methods for Describing Data." This provides the necessary background for normal probability plots, even for those who choose to delay Chapter 5 ("Summarizing Bivariate Data") until after the chapters on basic inferential methods.
- Many new examples and exercises that use data from current journals and newspapers have been added. In addition, more of the exercises specifically ask students to write (e.g., explaining reasoning, interpreting results, and commenting on important features of an analysis).

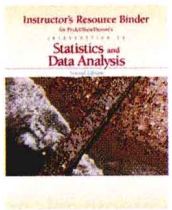
Ancillaries

For Students

A Student Suite CD provided with the book includes the following items: applets; InfoTrac© College Edition and Internet Exercises; links to both the Book Companion Web Site and the Internet Companion for Statistics by Michael Larsen; data sets formatted for MINITAB, Microsoft Excel, SPSS, SAS, JMP, and ASCII; and technology manuals designed for use with MINITAB, Excel, Graphing Calculator, JMP Intro, and SPSS. Also available are a student solutions manual and a separate activities workbook.



For Instructors



The following supplements are available to qualified adopters. Please contact your local Thomson ▪ Duxbury sales representative for details.

The Instructor's Suite CD includes everything featured on the Student Suite CD plus the Instructor's Solutions Manual for all exercises found in the text, Test Bank in Microsoft Word® format, and PowerPoint Presentations. Also available are the Instructor's Resource Binder, BCA Testing, and BCA Homework.

The Instructor's Resource Binder includes additional examples and additional resources for each chapter. A section titled "Data Explorations" contains examples of larger problems that are more investigative in nature and that involve integrating several topics from the course.

BCA Testing gives instructors the power to transform the learning and teaching experiences. BCA is fully integrated testing and course management software accessible to instructors and students anytime, anywhere. BCA uses correct statis-

tical notation and is delivered in a browser-based format without the need for any proprietary software or plug-ins. Results flow automatically to a grade book for tracking so that instructors will be better able to assess student understanding of the material before class or before an actual test.

BCA Homework with DuxStat facilitates classroom management, finally allowing instructors to test the way they teach. DuxStat assesses students through homework, on quizzes, or on exams, in the process of doing real data analysis on the Web. Student responses are automatically graded and entered into the BCA Gradebook, making it easy for the instructor to assign and collect homework over the Web.

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Roxy Peck
Chris Olsen
Jay Devore

Brief Contents

Contents