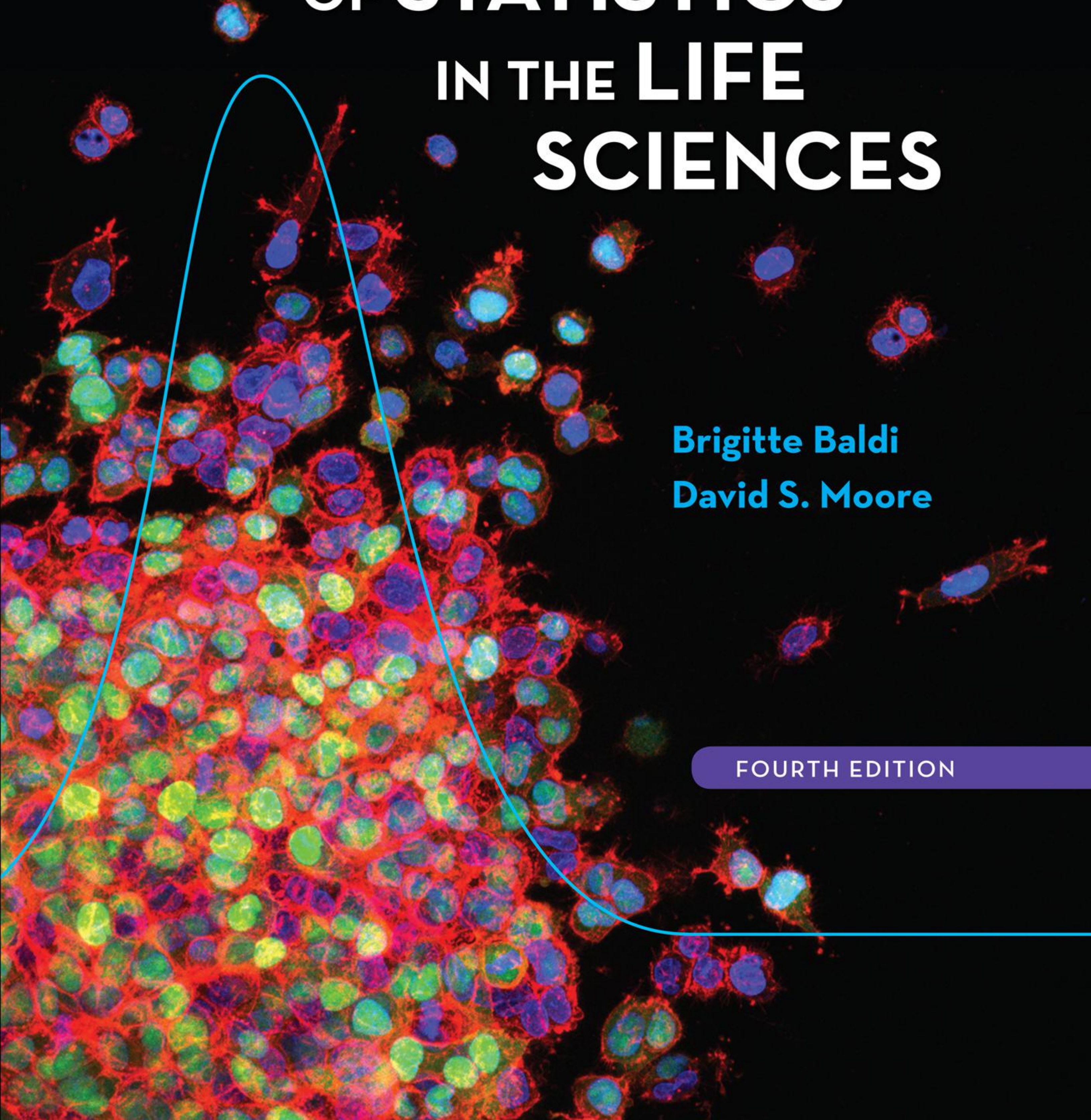
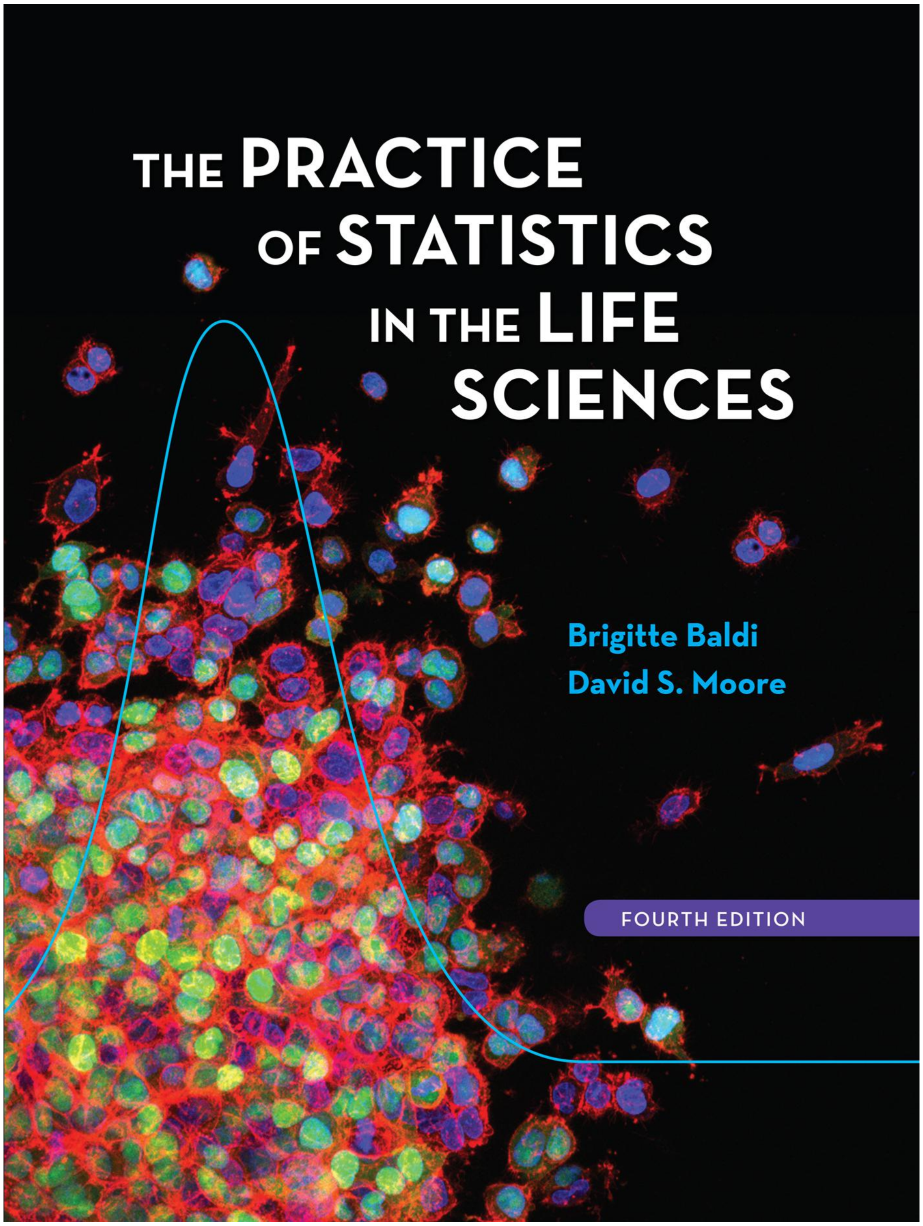
THE PRACTICE OF STATISTICS IN THE LIFE SCIENCES

Brigitte Baldi
David S. Moore

FOURTH EDITION

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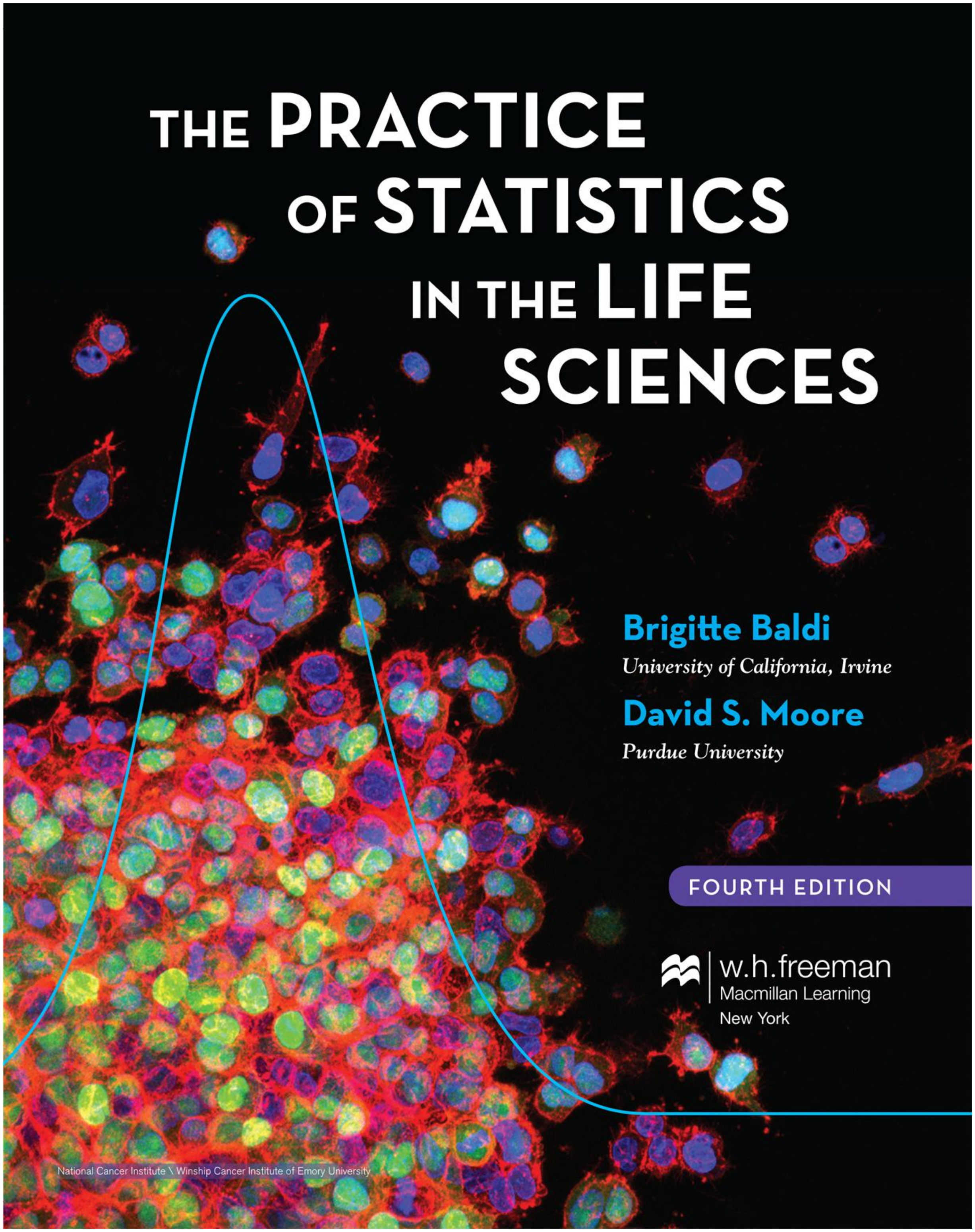
Macmillan Learning
New York



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Library of Congress Control Number: 2017945523

ISBN 978-1-319-06749-6 (EPUB)

W. H. Freeman and Company
One New York Plaza
Suite 4500
New York, NY 10004-1562
www.macmillanlearning.com

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INFERENCE ABOUT CATEGORICAL VARIABLES

INFERENCE ABOUT RELATIONSHIPS

Part IV Optional Companion Chapters (available on the *PSLS 4e* Companion Website)

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TO THE INSTRUCTOR: **About this Book**

THE PRACTICE OF STATISTICS IN THE LIFE SCIENCES

The Practice of Statistics in the Life Sciences, Fourth Edition (*PSLS 4e*) is an introduction to statistics for college and university students interested in the quantitative analysis of life science problems. Statistics has become an integral part of the life sciences, where its practice faces a specific set of challenges, such as observational studies with confounding variables and experiments with limited sample sizes. Consequently, students can greatly benefit from a teaching of statistics that is explicitly applied to their major. Fortunately, tailoring an introductory statistics course to a specific audience does not require fundamentally altering the statistical content if interesting and relevant examples are used to illustrate the statistical concepts.[1]

All examples and exercises in *PSLS* describe actual studies drawn from diverse areas of biology, such as physiology, brain and behavior, epidemiology, health and medicine, nutrition, ecology, and microbiology. Each new edition brings in recently published studies, a number of which cover topics of acute relevance. *PSLS 4e,* for instance, includes new problems on the Zika virus, the long-term effects of concussions, and patterns in global climate change. Instructors can choose to either cover a wide range of topics or select examples and exercises related to a particular field.

PSLS focuses on the applications of statistics rather than the mathematical foundation. This book is adapted from David Moore's best-selling introductory statistics textbook *The Basic Practice of*

Statistics (*BPS*). *BPS* was the pioneer in presenting a modern approach to statistics in a genuinely elementary text. Like *BPS*, *PSLS* emphasizes balanced content, working with real data, and statistical ideas. It does not require any specific mathematical skills beyond being able to read and use simple equations and can be used in conjunction with almost any level of technology for computations and graphs.

GAISE GUIDING PRINCIPLES

The American Statistical Association (ASA) endorses a set of recommendations for introductory statistics courses at the college level described in the Guidelines for Assessment and Instruction in Statistics Education (GAISE). Initially published in 2005,[2] the GAISE College Report was revised in 2016 to account for the "many changes in the world of statistics education and statistical practice since 2005."[3] Previous editions of *PSLS* followed the initial GAISE recommendations closely, and the fourth edition has been revised specifically with the 2016 GAISE update in mind. Here are the six GAISE recommendations for the teaching of introductory statistics and how they are implemented in *PSLS 4e*.

1. **Teach statistical thinking.** An introductory statistics course should help students develop the skills required to think critically about statistical issues and to approach statistical problems like a statistician. Statistical thinking should be taught as an investigative process that recognizes the need for data, the importance of data production, the omnipresence of variability, the quantification and explanation of variability, and the relevance of multivariate exploration.

   To this end, *PSLS* begins with data analysis (Chapters 1 to 5) and data production (Chapters 6 and 7) in Part I, then moves on to probability (Chapters 9 to 12) and the concepts of statistical inference (Chapters 13 to 15) in Part II, before eventually covering a variety of inference procedures (Chapters 17 to 25 and companion Chapters 26 to 28) in Parts III and IV. This sequence matches the investigative process of statistical problems and facilitates students' learning experience by starting with topics that are more familiar to them.

It is easy for students to become lost in the details of the procedures covered in separate chapters. In the end, however, students should come to realize that these various parts are all interconnected and necessary to solving statistical problems. To help them along, each chapter contains a summary section titled "**This Chapter in Context**" that specifically highlights how the concepts from the chapter relate to concepts introduced in earlier chapters and how they will figure into following chapters. For a wider perspective, a **Discussion** box in Chapter 15 describes the general statistical approach used to solve scientific problems in the context of the Nobel Prize–winning discovery of the bacterial origin of most peptic ulcers. This detailed historical and scientific account helps students see how the concepts they learn throughout the book come together to form a coherent science of data.

Pedagogically, many of the examples and exercises throughout *PSLS* are presented in the context of a "**four-step process**" (State, Plan, Solve, Conclude), depicted in Figure 1. This process models the whole statistical approach for students: Statistical problems originate in a real-world setting ("State") and require conclusions in the language of that setting ("Conclude"). Translating the problem into the formal language of statistics ("Plan") is a key to success. The graphs and computations needed ("Solve") are essential but are not the whole story. The four-step process (identified by a margin icon) appears throughout the text so as to foster the students’ ability to investigate statistical problems independently.

In this fourth edition, a greater emphasis has been placed, whenever appropriate, on the multivariate nature of statistics and the reliance on models. This is not to say that the topics covered in *PSLS* or the level at which they are covered has changed. *PSLS* remains an introductory statistics textbook meant to be easily accessible to students. Rather, the text explicitly points out multivariate patterns in context, to better familiarize students with this important aspect of statistical thinking.

2. **Focus on conceptual understanding.** A first course in statistics introduces many skills and it is important to ensure that students gain a deep understanding of the concepts behind them rather than a procedural knowledge of how to use a series of formulas like recipes. In practice (even if not always in the course), calculations and graphs are automated. Moreover, anyone who makes serious use of statistics will need some specific procedures not taught in his or her college statistics course. Thus, students should leave their first course with an understanding of the basic ideas of statistics, including the need for data, the importance of data production, the omnipresence of variability, the quantification and explanation of variability, and the limitations of statistical procedures.

ORGANIZING A STATISTICAL PROBLEM: THE FOUR-STEP PROCESS

STATE: What is the practical question, in the context of the real-world setting?

PLAN: What specific statistical operations does this problem call for?

SOLVE: Analyze the data with graphs and computations suitable for this problem.

CONCLUDE: Give your practical conclusion in the setting of the real-world problem.

CONFIDENCE INTERVALS: THE FOUR-STEP PROCESS

STATE: What is the practical question that requires estimating a parameter?

PLAN: Identify the parameter and choose a level of confidence.

SOLVE: Carry out the work in two phases:

1. **Check the conditions** for the interval you plan to use.
2. Obtain the **confidence interval**.

CONCLUDE: Return to the practical question to describe your results in this setting.

TESTS OF SIGNIFICANCE: THE FOUR-STEP PROCESS

STATE: What is the practical question that requires a statistical test?

PLAN: Identify the parameter, state the null and alternative hypotheses, and choose the type of test that fits your situation.

SOLVE: Carry out the test in two phases:

1. **Check the conditions** for the test you plan to use.
2. Obtain the **test statistic** and the ***P*-value**.

CONCLUDE: Return to the practical question to describe your results in this setting.

FIGURE 1 Overview of the “four-step process” used in PSLS.

PSLS aims to make clear the larger patterns and big ideas of statistics in the context of learning specific skills and working with data. Many of the big ideas are summarized in graphical outlines in **Statistics in Summary** figures within the **Review Chapters**. The Review Chapters at the end of Parts I, II, and III offer a comprehensive summary of the important concepts and skills that students should have mastered. Review Chapters now also provide more comprehensive exercises that require applying concepts learned across a number of chapters.

Throughout the text, numerous cautionary statements are included to warn students about common confusions and misinterpretations. A handy "Caution" icon in the margin calls attention to these warnings. In addition, two Discussion boxes address how a meaningful interpretation must rely on a comprehensive analysis of the data available: The Discussion box in Chapter 10 addresses the interpretation of conditional probabilities in the context of diagnostic and screening tests, while the Discussion box in Chapter 20 helps students assess and interpret health risks beyond the *P*-value of a hypothesis test.

3. **Integrate real data with a context and purpose.** The study of statistics is supposed to help students work with data in their varied academic disciplines and later employment. This is particularly important for students in the life sciences, because they are asked to collect and analyze data in their laboratory courses and elective undergraduate research. *PSLS* prepares students by providing real (not merely realistic) data from many areas of the life sciences, with sources cited at the back of the book. Data are more than mere numbers—they are numbers with a context that should play a role in making sense of the numbers and in stating conclusions. Examples and exercises in *PSLS* give enough background to allow students to consider the meaning of their analysis in context.

PSLS provides approximately 50 examples and exercises per chapter, ranging in complexity from studies with summary statistics or small data sets for in-class use to large data sets (with several variables and a fairly large number of subjects) more suitable for lab work or assignments. In addition, two Discussion boxes address in greater depth some important issues when dealing with real data: The Discussion box in Chapter 1 exposes students to some of the challenges of data entry and validation, while the Discussion box in Chapter 2 explains how to recognize different types of outliers and how to deal with them legitimately.

Real and relevant studies are also important to illustrate the usefulness of statistics and to generate enthusiasm in students.[4] A very small number of examples and exercises in *PSLS* are, for specific pedagogical purposes, theoretical or purely computational. All others describe actual life science studies drawn from scientific and news reports published in the years immediately before each new edition. The studies are selected for both their statistical relevance and general interest. This latest edition, for instance, addresses the U.S. opioid health crisis, the pathology of the Zika virus and possible treatment, Magellanic penguins, and the neurological basis for the infamous photo of a dress that looks black-and-blue to some people and white-and-gold to others.

4. **Foster active learning.** How students learn in the classroom is the domain of the instructor. *PSLS* offers a number of opportunities to help instructors foster active learning. After a summary of the chapter's key concepts, a set of **Check Your Skills** multiple-choice items with answers in the back of the book lets students assess their grasp of basic ideas and skills. These problems can also be used in a "clicker" classroom response system to enable class participation. Additional **clicker**

questions are available to instructors on the book's Companion Website.

PSLS also provides many examples and exercises based on small data sets or summary statistics that can be solved during class in a reasonable amount of time. The Review Chapters offer links to regularly updated **online data sources** (including some with built-in data visualization tools) to support classroom discussion. Instructors interested in creating a review session at the end of the term can build on a set of short exercises in Chapter 25 requiring students to select an inference procedure appropriate for the particular data, design, and purpose of various studies. For courses that include a computer lab component, the large data set exercises offer an opportunity for hands-on analysis with statistical software. There is no short answer given to students for these specific exercises, so that instructors can elect to assign them for a grade.

Visual representations of new concepts can also help students learn through experience. On the *PSLS* Companion Website, instructors and students will find a set of interactive **applets** created to our specifications. These applets are designed primarily to help students in learning statistics, rather than in doing statistics, and can be effective tools for classroom demonstrations of concepts such as the influence of outliers and sample size on various computations.

5. **Use technology to explore concepts and analyze data.** Technology is now an integral part of the practice of statistics and this reality should be reflected in its teaching. As an added bonus, automating graphs and calculations increases students' ability to complete problems that use real data (including those with larger, more complex data sets) and helps them focus on concepts and problem recognition rather than mechanics.

   PSLS does not require or recommend any particular technology. Instead, outputs from a variety of platforms and programs (applets, CrunchIt!®, Excel, JMP, Minitab, R/Rcmdr, SPSS[i], TI-83/84) are shown throughout the book, with similarities and notable differences pointed out, to help students familiarize themselves with **technology outputs**. The choice of technology and the extent of its use in the classroom and for assignments are often dictated by practical and financial considerations specific to each course and, therefore, are best left to the instructor. *PSLS 4e* now provides on its Companion Website technical instructions organized by chapter for CrunchIt!®, Excel, JMP, Minitab, R, SPSS, and the TI-83/84 in support of that choice. All **data** sets in *PSLS* are also available electronically in various formats to facilitate students' active learning.

A quite different use of technology appears in the interactive applets available on the Companion Website. Some examples and exercises in the text use applets, and they are marked with a dedicated icon in the margin.

6. **Use assessments to improve and evaluate student learning.** *PSLS* provides a wide variety of exercises that can be used to create a mix of formative and summative assessments. Within chapters, exercises progress from straightforward applications (Apply Your Knowledge short exercises and Check Your Skills multiple-choice items) to comprehensive end-of-chapter exercises. Complementing this set, exercises in the three Review Chapters enlarge the statistical context beyond that of the immediate lesson. (Many instructors will find that the Review Chapters appear at convenient points for pre-exam review.)

   Short answers to odd-numbered exercises are provided to students (at the back of the book or via a click in the e-Book) for self-assessment. At the opposite end of the spectrum, exercises marked with the "Large Data Set" icon are never offered with short answers (regardless of placement) so that they may be used for graded assignments or in-class activities. These exercises rely on larger and slightly

more complex data sets designed to provide a richer data experience to students. A few of these exercises are located at the end of individual chapters but, for the most part, they can now be found in Review Chapters to facilitate comprehensive analyses that are not limited by chapter boundaries.

WHAT'S NEW IN THE FOURTH EDITION?

This fourth edition of *PSLS* offers many new examples and exercises, as well as numerous opportunities to refocus the exposition to align with developments in statistics education. Here are, specifically, some of the major changes:

- **New exercises and examples.** As always, *PSLS* aims to provide an abundance and variety of current and interesting examples and exercises. The fourth edition has more than 400 new or updated exercises and examples, representing roughly 30% of the material in the third edition's main chapters. On the practical side, having many new exercises means that homework assignments can be varied over time to avoid "recycled paper" issues. To further help with this issue, Review Chapters in *PSLS 4e* include a set of links to regularly updated online data sources relevant to the life sciences that can be used to create easily renewed assignments.

  New exercises and examples also help instructors avoid the boredom of teaching the same old material and help students better appreciate the relevance of the statistical approach when it is applied to current issues. Some of the new problems with a medical or epidemiological focus include studies of the Zika virus (ranging from the association with microcephaly to a potential treatment), the U.S. opioid epidemic, the relationship between concussion and long-term brain damage, and approaches to smoking cessation. Behavioral studies include an ethically questionable Facebook experiment and and a study of the infamous photo of a dress that looks black-and-blue to some people and white-and-gold to others. *PSLS 4e* also presents studies of ant speeds and snow geese flight, adds two new large data sets on animal morphology (carpenter ants and monarch butterflies), describes plastic–eating bacteria that may help reduce plastic pollution, and covers several studies related to patterns of global climate change.

Beyond the studies themselves, the actual exposition of the concepts in examples and the type of questions asked in exercises have undergone some subtle yet important changes in *PSLS 4e*. The reason for this is pedagogical: Statistics is an evolving discipline and the field has seen substantial pedagogical updates in recent years. The 2016 GAISE update and the corresponding approach taken in *PSLS 4e* have already been addressed in depth. An additional development that occurred in 2016 was the release by the American Statistical Association (ASA) of an official statement on *P*-values. Following is a description of the statement and the associated changes in *PSLS 4e*.

- **Treatment of statistical significance.** Some misuses of statistical ideas have over time culminated in a problem of reproducibility and replicability of scientific conclusions and an eroding trust in statistics. Because many of these issues centered on *P*-values, the ASA published an official statement on *P*-values.[5] This 2016 ASA statement is brief, written to be accessible beyond the statistical community, and makes a great reading assignment for students in an introductory statistics course (Exercise 16.17, page 410, is specifically designed for this purpose). The statement clarifies what *P*-values do and do not imply, and points to their appropriate versus inappropriate uses.

Of particular concern is the fairly common reliance (among students, scientists, and publishers) on "$P < 0.05$" as a sort of "bright-line" threshold bestowing scientific worth. In a self-reinforcing loop, this practice became ever more widespread as statistics courses taught $\alpha = 0.05$ precisely because it was so widespread. In an attempt to break the cycle, *PSLS 4e* explicitly de-emphasizes the omnipresence of the significance level α (0.05 or other), expecting instead that students evaluate the strength of the evidence against the null hypothesis. Students should understand that, when the conditions for inference are met, and given similar study settings, a *P*-value of 0.0006 provides stronger evidence against H_0 than a *P*-value of 0.047, and that neither is a judgment of practical importance.

Beyond issues of significance level, the true meaning of *P*-values is often misunderstood. In this edition, the actual definition of a *P*-value is explicitly stated in every inference chapter to remind students of what can and cannot be concluded from a *P*-value and that *P*-values come with assumptions that must be checked. These caveats are not mere side notes; rather, they are fundamental to the use of statistical inference.

- **"Using Technology."** Previous editions of *PSLS* covered the use of technology for computations in a separate section titled "Using Technology," typically located toward the end of the chapter. *PSLS 4e* employs a different approach. Technology is now part of all examples for which it is relevant, and it is fully integrated with a discussion of study design, choice of methodology, and conclusion in context. Computations are still outlined and explained explicitly for every example, but they no longer occupy the center stage. Furthermore, the use of tables of critical values is now demonstrated in optional sections within their relevant chapters, to serve courses that rely on them as an alternative to technology in the classroom.[6]

The new approach models for students a more realistic practice of statistics. It also lets students focus on all the truly challenging aspects of statistics (such as stating an appropriate and comprehensive conclusion in context) that no amount of technology can accomplish for them.

- **Parts and Review Chapters.** The flow of topics in *PSLS 4e* remains unchanged, but the organization of topics into parts reflects a more thematic content-grouping that is also likely to better fit the format of a statistics course with regular projects or exams. Specifically, the chapters on data acquisition (formerly Chapters 7 and 8) have been brought into Part I, renamed "Collecting and Exploring Data." Part II is now titled "From Chance to Inference" and is more fundamentally focused on issues related to probability.

  The new grouping reflects the changing nature of our student population, which is more likely to have already encountered many of the concepts of descriptive statistics covered in Chapters 1 through 5. To this end, Chapters 1 and 2 in particular have been updated to de-emphasize hand-computations of summary statistics and to present a greater variety of graphical displays that students are likely to encounter in news reports and scientific publications.

  The new chapter grouping also creates more thematically homogeneous Review Chapters, allowing for comprehensive problems that draw from several chapters at once. Similarly, most Large Data Set Exercises (including several brand-new data sets) have been placed in the Review Chapters to facilitate comprehensive analyses that are not limited by chapter boundaries. Lastly, for instructors who like to assign projects, links to regularly updated online data sources round up the collection.

- **Discussion exercises.** Instructors have told us that, while they found the various Discussion boxes throughout *PSLS* very interesting, they also found them challenging to officially "assign." The fourth edition now contains exercises following each Discussion box that specifically ask students to consider which aspects of the discussion relate to a particular problem.
- **Technology appendices.** Over the years, numerous instructors have indicated that short technology instructions would be helpful for students learning to use a particular technology for their assignments. We are excited to announce that the Companion Website for *PSLS 4e* now provides technical instructions, organized by chapter, for CrunchIt!®, Excel, JMP, Minitab, R, SPSS, and the TI-83/84. For instructors using our online homework platforms, video instructions remain available as well.

WHY DID YOU DO THAT?

There is no single best way to organize the presentation of statistics to beginners. That said, our choices reflect thinking about both content and pedagogy. Here are comments on several "frequently asked questions" about the order and selection of material in *PSLS 4e.*

Why not begin with data production? It is certainly reasonable to do so—the natural flow of a planned study is from design to data analysis to inference. In their future employment, though, most students will use statistics mainly in settings other than planned research studies. Students also come into an introductory statistics course having some experience with the basics of descriptive statistics, so it makes sense pedagogically to start with this topic.

Why not delay correlation and regression until late in the course? *PSLS 4e* begins by offering experience working with data and gives a conceptual structure for this nonmathematical but essential part of statistics. Students profit from more experience with data and from seeing the conceptual structure worked out in relationships among variables as well as describing single-variable data. Correlation and least-squares regression are very important descriptive tools, and they are often used in settings where there is no population-sample distinction, such as studies based on state records or average species data. Perhaps most important, the *PSLS* approach asks students to think about what kind of relationship lies behind the data (confounding, lurking variables, association doesn't imply causation, and so on), without overwhelming them with the demands of formal inference methods. The same argument can be made for introducing two-way tables first in the context of exploratory data analysis. Of course, instructors sometimes need to adapt their syllabus to suit nonpedagogical issues such as course length and sequence. The writing in *PSLS* is modular enough that instructors can easily pick a set of chapters and an order that works for them.

What about probability? Chapters 9, 11, and 13 present—in a simple format—the ideas of probability and sampling distributions that are needed to understand inference. These chapters go from the idea of probability as long-term regularity, to the concrete use of basic probability models, to the idea of the sampling distribution of a statistic. The central limit theorem appears in the context of discussing the sampling distribution of a sample mean. The *optional* Chapters 10 and 12 cover the more advanced topics of independence and conditional probability, and the binomial and Poisson distributions.

Depending on your student audience, you may want to omit one or both of these optional chapters. Experienced teachers recognize that students find probability difficult, and research has shown that this is true even for professionals. If a course is intended for medical school or premed students, for instance, the concept of conditional probability is very relevant because it is a key part of diagnosis that both doctors and patients have difficulty interpreting.[7] However, attempting to present a substantial introduction to probability in a data-oriented statistics course for students who are not mathematically trained is a difficult challenge. Instructors should keep in mind that formal probability does not help students master the ideas of inference as much as we teachers often imagine, and it depletes reserves of mental energy that might better be applied to essential statistical ideas.

Why use the *z* procedures for a population mean to introduce the reasoning of inference? This is a pedagogical issue, rather than a question of statistics in practice. At some point in the golden future, we may start with resampling methods, as permutation tests make the reasoning of tests clearer than any traditional approach. For now, the main choices are z for a mean and z for a proportion.

The z procedures for means are pedagogically more accessible to students. We can say up front that we will explore the reasoning of inference in an overly simple setting. Remember, exactly Normal populations and true simple random samples are as unrealistic as known σ, especially in the life sciences. All the issues of practice—robustness against lack of Normality and application when the data aren't a simple random sample, as well as the need to estimate σ—are put off until, with the reasoning in hand, we discuss the practically useful t procedures. This separation of initial reasoning from messier practice works well.

In contrast, starting with inference for p introduces many side issues: no exact Normal sampling distribution, but a Normal approximation to a discrete distribution; use of $\widehat{p}$ in both the numerator and the denominator of the test statistic to estimate both the parameter p and $\widehat{p}$'s own standard deviation; loss of the direct link between test and confidence interval. In addition, we now know that the traditional z confidence interval for p is often grossly inaccurate, as explained in the following section. Lastly, major polling organizations such as Gallup and Pew now report substantially different margins of error (accounting for data weighing), making it increasingly challenging to show students real-life applications of the *z* method for a proportion.

Furthering changes initiated in previous editions, *PSLS 4e* covers the *z* procedures for a population mean at a mostly conceptual level, so as to introduce the reasoning of inference. Instructors may choose to pair these conceptual chapters with Chapter 17 on the *t* procedures for a population mean, thereby combining theory and practice.

Why does the presentation of inference for proportions go beyond the traditional methods? Recent computational and theoretical work has demonstrated convincingly that the standard confidence intervals for proportions can be trusted only for very large sample sizes. It is hard to abandon old friends, but the graphs in section 2 of the paper by Brown, Cai, and DasGupta in the May 2001 issue of *Statistical Science* are both distressing and persuasive.[8] The standard intervals often have a true confidence level much less than what was requested, and requiring larger samples encounters a maze of "lucky" and "unlucky" sample sizes until very large samples are reached. Fortunately, there is a simple cure: Just add two successes and two failures to your data. (Therefore, no additional software tool is required for this procedure.) We present these "plus four intervals" in Chapters 19 and 20, along with guidelines for use.

Why haven't the companion Chapters 26 to 28 been updated at this time? A new edition takes more than a year to edit and ready for print (in addition to finding new studies and writing new material). Because the companion chapters aren't printed, we have chosen to focus first on the core text chapters and the synchronous production of our homework system. The companion chapters will be updated between editions, and made available on the Companion Website.

Why didn't you cover Topic X? Introductory texts ought not to be encyclopedic. Including each reader's favorite special topic results in a text that is formidable in size and intimidating to students. The topics covered in *PSLS* were chosen because they are the most commonly used in the life sciences and they are suitable vehicles for learning broader statistical ideas. Three chapters available on the Companion Website cover more advanced inference procedures. Students who have completed the core of *PSLS* will have little difficulty moving on to more elaborate methods.

Acknowledgments

We are grateful to colleagues from two-year and four-year colleges and universities who commented on successive drafts of the manuscript. Special thanks are due to Marjorie Bond of Monmouth College, who read the manuscript and checked its accuracy. We also wish to thank those who reviewed the fourth edition:

Reza O. Abbasian,
Texas Lutheran University

James Robert Adcock,
University of Waterloo

Amei Amei,
University of Nevada, Las Vegas

Alexander Aue,
University of California, Davis

Steve Bacinski,
Davenport University

Jennifer Beineke,
Western New England University

Margaret Bryan,
University of Missouri, Columbia

Grace Chen,
Idaho State University

Tyler Cook,
University of Central Oklahoma

William M. Cook,
St. Cloud State University

Dina Dawoud,

University of Waterloo
Lelys Bravo de Guenni,
University of California, Santa Cruz
Christiana Drake,
University of California, Davis
Donna Dueker,
California State University, Dominguez Hills
Diane Fisher,
University of Louisiana at Lafayette
Leszek Gawarecki,
Kettering University
Jose Guardiola,
Texas A&M University?Corpus Christi
Abeer Hasan,
Humboldt State University
Leslie Hendrix,
University of South Carolina
Heather J. Hoffman,
George Washington University
Dawn Holmes,
University of California, Santa Barbara
Yi Huang,
University of Maryland, Baltimore County
Michelle Jeitler,
Marietta College
Zhenyu Jia,
University of Akron
Ravi Khattree,
Oakland University
Jong S. Kim,

Portland State University
Yoon G. Kim,
Humboldt State University
Elizabeth Young Kolodziej,
Texas A&M University
Chris Lacke,
Rowan University
Maureen Lahiff,
University of California, Berkeley
Suhwon Lee,
University of Missouri, Columbia
Lia Liu,
University of Illinois at Chicago
Tatiana Mihaylova,
Bellevue College
Christopher Mosbo,
State University of New York at Oswego
Linda Myers,
Harrisburg Area Community College
Leonard Onyiah,
St. Cloud State University
Adriana Perez,
University of Texas Health Science Center at Houston
Amber Powell,
State University of New York at Fredonia
Tiantian Qin,
Purdue University
Rachel Rader,
Ohio Northern University
Laurence D. Robinson,
Ohio Northern University

Julie Roy,
University of Louisiana at Lafayette
Laura M. Schultz,
Rowan University
Ye Shen,
University of Georgia
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University of Cincinnati
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Mount Royal University
Kyle T. Turner,
University of Georgia
Jennifer Waugh,
University of Western Ontario
Daniel Weiner,
Boston University
Qiang Wu,
East Carolina University

We are also particularly grateful to Karen Carson, Tom DeMarco, Katrina Mangold, Andy Newton, Lisa Kinne, Paul Rohloff, Robin Fadool, Naomi Kornhauser, Marco Baldi, and the other editorial and design professionals who have helped make this textbook a reality.

Finally, our thanks go to the many students whose compliments and complaints have helped improve our teaching over the years.

Brigitte Baldi and David S. Moore

Media and Supplements

INTRODUCING SAPLINGPLUS FOR PSLS 4E!

The new fourth edition of *PSLS* is now in SaplingPlus, an extraordinary new online resource providing the richest, most completely integrated text/media learning experience yet. SaplingPlus combines Macmillan's StatsTools, powerful multimedia resources, and text-specific machine-gradable exercises for *PSLS* with an integrated e-Book and the robust exercise library of Sapling Learning.

Created and supported by educators, **Macmillan Learning's Instructional Online Homework** drives student success and saves educators time. More than 1000 exercises contain full solutions and general feedback, and more than 800 exercises also contain hints, answer-specific feedback, and solutions, ensuring that students find the help they need, wherever they need it. With SaplingPlus, every problem counts.

ASSETS INTEGRATED INTO SAPLINGPLUS INCLUDE THE FOLLOWING:

Interactive e-Book provides powerful study tools for students, video and multimedia content, and easy customization for instructors. Students can search, highlight, and bookmark specific information, making it easier to study and access key content.

LearningCurve provides students and instructors with powerful adaptive quizzing, a game-like format, direct links to the e-Book, and instant feedback. The quizzing system features questions tailored specifically to the text and adapts to students' responses, providing material at different difficulty levels and topics based on student performance.

StatTutor Tutorials offer multimedia tutorials that explore important concepts and procedures in a presentation that combines video, audio, and interactive features. The newly revised format includes built-in assignable assessments and a bright new interface.

Statistical Applets give students hands-on opportunities to familiarize themselves with important statistical concepts and procedures in an interactive setting that allows them to manipulate variables and see the results graphically. Icons in the textbook indicate when an applet is available for the material being covered.

StatBoard Videos are brief whiteboard videos that illustrate difficult topics through additional examples, written and explained by an expert group of statistics educators.

Statistical Video Series consists of StatClips, StatClips Examples, and Statistically Speaking "Snapshots." View animated lecture videos, whiteboard lessons, and documentary-style footage that illustrate key statistical concepts and help students visualize statistics in real-world scenarios.

NEW! Technology Appendices for each chapter give detailed instructions on how to perform key statistical procedures in various statistical software packages including TI-83/84 calculators, Minitab, Excel, JMP, SPSS, R, Rcmdr, and CrunchIt!®. Also available on the *PSLS* Companion Website.

Video Technology Manuals, available for TI-83/84 calculators, Minitab, Excel, JMP, SPSS, R, Rcmdr, and CrunchIt!®, provide brief instructions for using specific statistical software.

CrunchIt!® is Macmillan Learning's own web-based statistical software that allows users to perform all the statistical operations and graphing needed for an introductory statistics course and more. It saves users time by automatically loading data from *PSLS*, and it provides the flexibility to edit and import additional data.

JMP Student Edition (developed by SAS) is easy to learn and contains all the capabilities required for introductory statistics. JMP is the leading commercial data analysis software of choice for scientists, engineers, and analysts at companies throughout the world (for Windows and Mac).

Data files are available in JMP, ASCII, Excel, TI, Minitab, SPSS, R, and CSV formats.

EESEE Case Studies (*Electronic Encyclopedia of Statistical Examples and Exercises*) developed by The Ohio State University Statistics Department, teach students to apply their statistical skills by exploring actual case studies using real data.

Student Solutions Manual provides solutions to the odd-numbered exercises in the text.

Instructor's Guide with Solutions includes teaching suggestions, chapter comments, and detailed solutions to all exercises. Available to instructors only.

Test Bank offers hundreds of multiple-choice questions. Available to instructors only.

Lecture Slides offer a customizable, detailed lecture presentation of statistical concepts covered in each chapter of *PSLS*. Available to instructors only.

ADDITIONAL RESOURCES AVAILABLE WITH PSLS:

Companion Website www.macmillanlearning.com/psls4e

This open-access website includes:

- Statistical applets
- Data files
- Companion chapters covering further topics in ANOVA, nonparametric tests, and multiple and logistic regression
- Selected *EESEE* Case Studies that are referenced in the text
- Technology Appendices for each chapter

Instructor access to the Companion Website requires user registration as an instructor and features all the open-access student web materials, plus:

- Instructor's Guide with Solutions
- Downloadable Test Bank specific to each chapter in *PSLS*
- Lecture Slides specific to each chapter in *PSLS*
- iClicker Questions specific to each chapter in *PSLS*
- Image Slides containing all textbook figures and tables

Special Software Package: Student versions of JMP are available for packaging with the text. JMP is available inside SaplingPlus at no additional cost. Contact your Macmillan Learning representative for information or visit www.macmillanlearning.com.

CrunchIt!®: With a course adoption, instructors may provide CrunchIt!® access at no cost to students. Please contact your Macmillan Learning representative to receive a course access code for CrunchIt!®

i-clicker is a two-way radio-frequency classroom response solution developed by educators for educators. Each step of i-clicker's development has been informed by teaching and learning. To learn more about packaging i-clicker with this textbook, please contact your local sales representative or visit www.iclicker.com.

TO THE STUDENT: **Statistical Thinking**

Statistics is about data. Data are numbers, but they are not "just numbers." **Data are numbers with a context.** The number 7.5, for example, carries no information by itself. But studies of sleep patterns[1] indicate that a child in middle school who sleeps 7.5 hours on most nights is likely not getting enough sleep, yet that same amount of sleep is appropriate for most adults. The context engages our background knowledge and allows us to make judgments; it makes the number informative.

Statistics is the science of data. To gain insight from data, we analyze the data with various graphs and computational approaches. In essence, graphs and calculations are guided by ways of thinking that amount to educated common sense. Let's begin our study of statistics with an informal look at some principles of statistical thinking.

DATA BEAT ANECDOTES

An anecdote is a striking story that sticks in our minds exactly because it is striking. Anecdotes humanize an issue, but they can be misleading.

Does living near power lines cause leukemia in children? The National Cancer Institute spent 5 years and $5 million gathering data on this question. The researchers compared 638 children who had leukemia with 620 who did not. They went into the homes and measured the magnetic fields in the children's bedrooms, in other rooms, and at the front door. They recorded facts about power lines near the family home and also near the mother's residence when she was pregnant. Result: No connection between leukemia and exposure to magnetic fields of the kind produced by power lines. The editorial that accompanied the study report in the *New England Journal of Medicine* thundered, "It is time to stop wasting our research resources" on the question.[2]

Now compare the effectiveness of a television news report of a 5-year, $5 million investigation against a televised interview with an articulate mother whose child has leukemia and who happens to live near a power line. In the public mind, the anecdote wins every time. This is why, for instance, many parents worldwide refuse to vaccinate their children against potentially devastating childhood diseases, despite the countless studies showing *no association between vaccines and autism.*[3] A statistically literate person knows better. **Data are more reliable than anecdotes, because they systematically describe an overall picture rather than focus on a few incidents.**

WHERE THE DATA COME FROM IS IMPORTANT

The advice columnist Ann Landers once asked her readers, "If you had it to do over again, would you have children?" A few weeks later, her column was headlined "70% OF PARENTS SAY KIDS NOT WORTH IT." Indeed, 70% of the nearly 10,000 parents who wrote in said they would not have children if they could make the choice again. Do you believe that 70% of *all* parents regret having children?

You shouldn't. The people who took the trouble to write Ann Landers are not representative of all parents. Their letters showed that many of them were angry at their children. All we know from these data is that there are some unhappy parents out there. A statistically designed poll, unlike Ann Landers's appeal, targets specific people chosen in a way that gives all parents the same chance to be asked. Such a poll showed that 91% of parents *would* have children again. Where data come from matters a lot. If you are careless about how you get your data, you may announce 70% “no” when the truth is about 90% “yes.”

Here’s another question: *Should episiotomy be a routine part of childbirth?* Episiotomy is surgical cutting of the skin and muscles between the vagina and the rectum that is sometimes performed during childbirth. Until recently, it was one of the most common surgical procedures performed in women in the United States. The idea was that a sharp incision ought to be better for the mother than the possibility of a natural tearing.

However, recent clinical trials and epidemiological studies have shown no benefit of episiotomy unless the baby’s health requires accelerated delivery or a large natural tearing seems likely. In fact, these studies indicate that episiotomy is associated with longer healing times and increased rates of complications, including infection, extensive tearing, pain, and incontinence.[4]

To get convincing evidence on the benefits and risks of episiotomy, we need unbiased data. Proper epidemiological studies and clinical trials (controlled, randomized medical experiments) rely on randomness of patient or treatment selection to avoid bias. These careful studies of the risks and benefits of routine episiotomy can be trusted because they had sound data collection designs. As a result, in 2006, the American Congress of Obstetricians and Gynecologists recommended against routine episiotomy.

The most important information about any statistical study is how the data were produced. Only surveys that are statistically designed can be trusted. Only randomized experiments can give convincing evidence that an alleged cause really does account for an observed effect.

BEWARE THE LURKING VARIABLE

Energy drinks contain high levels of caffeine, which we know can temporarily boost alertness but can also cause sleep problems later on. A survey of U.S. service members in a combat environment in Afghanistan showed that those consuming energy drinks three or more times a day slept less, had more sleep disruptions, and were more likely to fall asleep on duty than those consuming fewer or no energy drinks.[5] What shall we make of this finding? Among service members in combat deployment, does the frequent consumption of energy drinks impair sleep or do individuals with impaired sleep consume more energy drinks to stay alert on the job? The answer may well be both, in a self-reinforcing loop. It is also possible that other factors, such as high stress, both interfere with sleep and create a desire for heightened alertness from energy drinks. A statistician knows that a causal link cannot be established here, because the data from this survey are simply observations.

Should women take hormones such as estrogen after menopause, when natural production of these hormones ends? In 1992, several major medical organizations said “yes.” In particular, women who took hormones seemed to reduce their risk of a heart attack by 35% to 50%. But in 2002, the National Institutes of Health declared these findings wrong. Use of hormones after menopause immediately plummeted. Both recommendations were based on extensive studies. What happened?

The evidence in favor of hormone replacement came from a number of *observational studies* that compared women who were taking hormones with others who were not. But women who choose to take hormones are very different from women who do not: They are richer and better educated and see doctors more often. These women do many things to maintain their health. It isn’t surprising that they have fewer heart attacks.

We can’t conclude that hormone replacement reduces heart attacks, just because we see a relationship in the data. Education and affluence are *lurking variables,* background factors that help explain the relationship between hormone replacement and good health.

Almost all relationships between two variables are influenced by other variables lurking in the background. To understand the relationship between two variables, you must often look at other variables. Careful statistical studies try to think of and measure possible lurking variables so as to correct for their influence. As the hormone saga illustrates, this is not always done. News reports often ignore possible lurking variables that might ruin a good headline. The habit of asking “What might lie behind this relationship?” is part of thinking statistically.

Another way to address the effect of lurking variables is by designing careful *experiments.* Several experiments randomly assigned volunteer women either to hormone replacement or to dummy pills that looked and tasted the same as the hormone pills. By 2002, these experiments agreed that hormone replacement does *not* reduce the risk of heart attacks, at least for older women. Faced with this better evidence, medical authorities changed their recommendations.[6]

ALWAYS LOOK AT THE DATA

Yogi Berra said it best: “You can observe a lot by just watching.” That’s a motto for learning from data. **A few carefully chosen graphs are often more instructive than great piles of numbers.**

Let’s look at some data. Figure 1 displays a histogram of the body lengths of 56 perch (*Perca fluviatilis*) caught in a Finnish lake.[7] Each bar in the graph represents how many perch had a body length between two values on the horizontal axis. For example, the tallest bar indicates that 17 perch had a body length between 20 and 25 centimeters (cm).