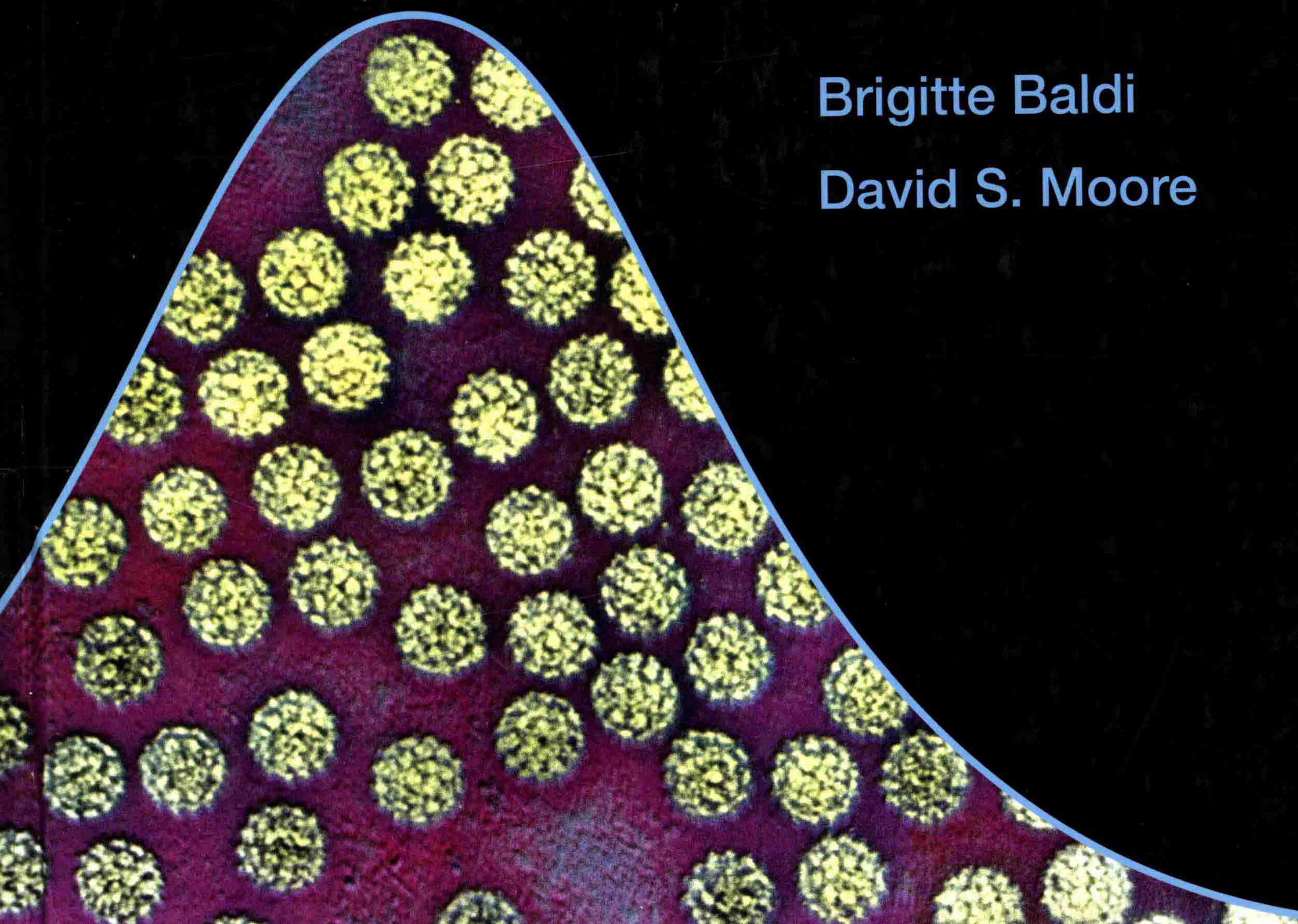
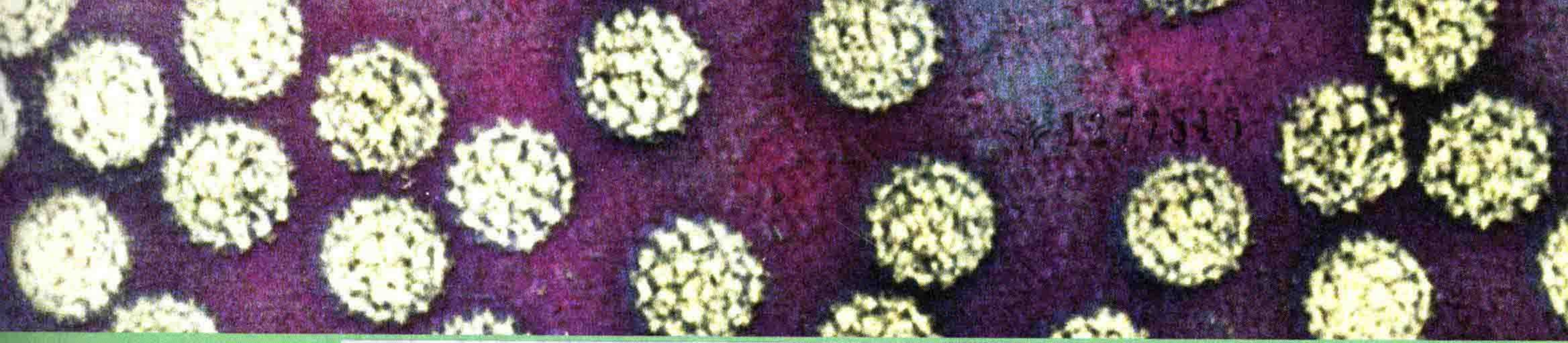
THIRD EDITION

The Practice of Statistics in the Life Sciences

Brigitte Baldi
David S. Moore





THIRD EDITION

The Practice of Statistics in the Life Sciences

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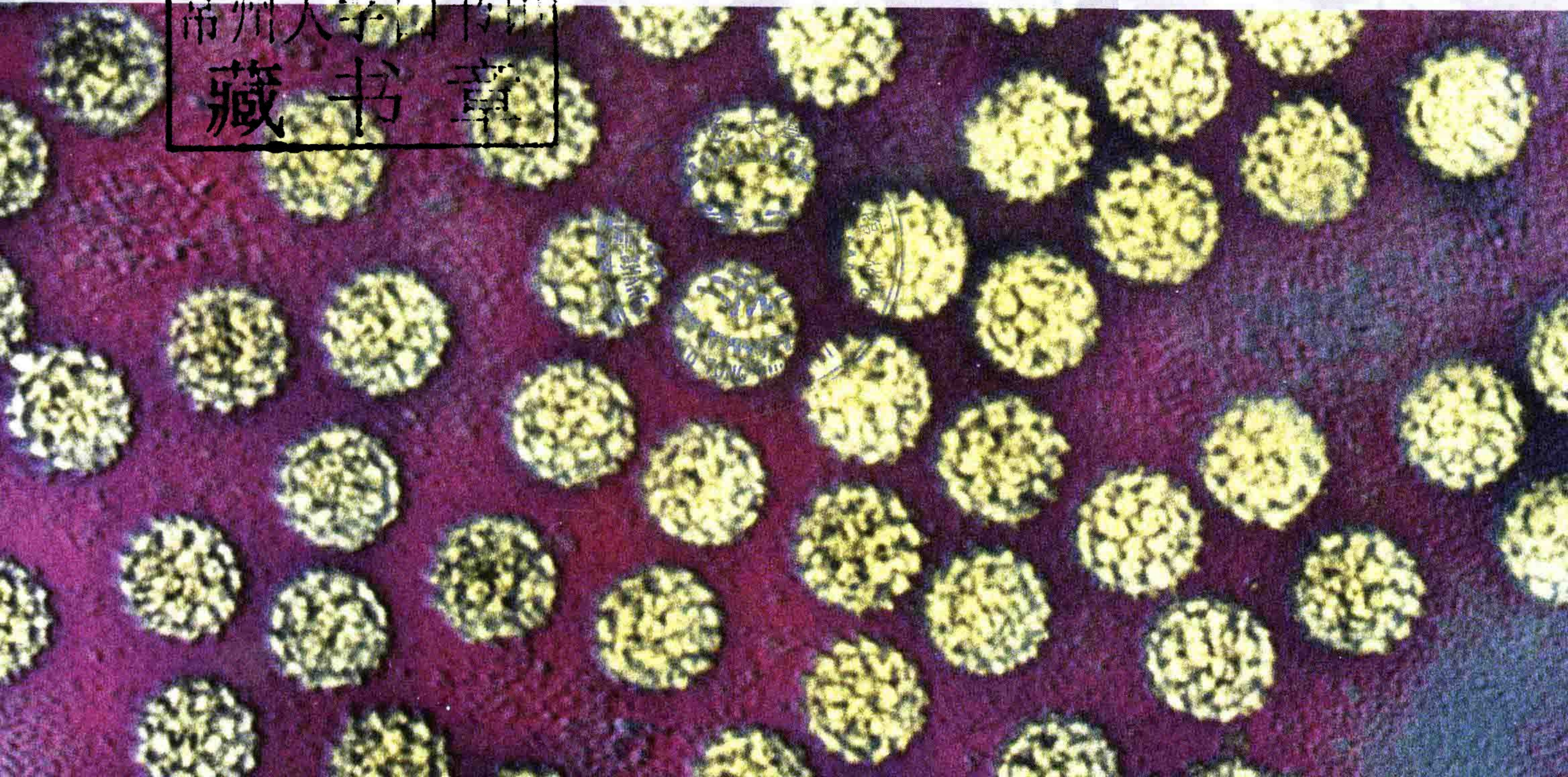

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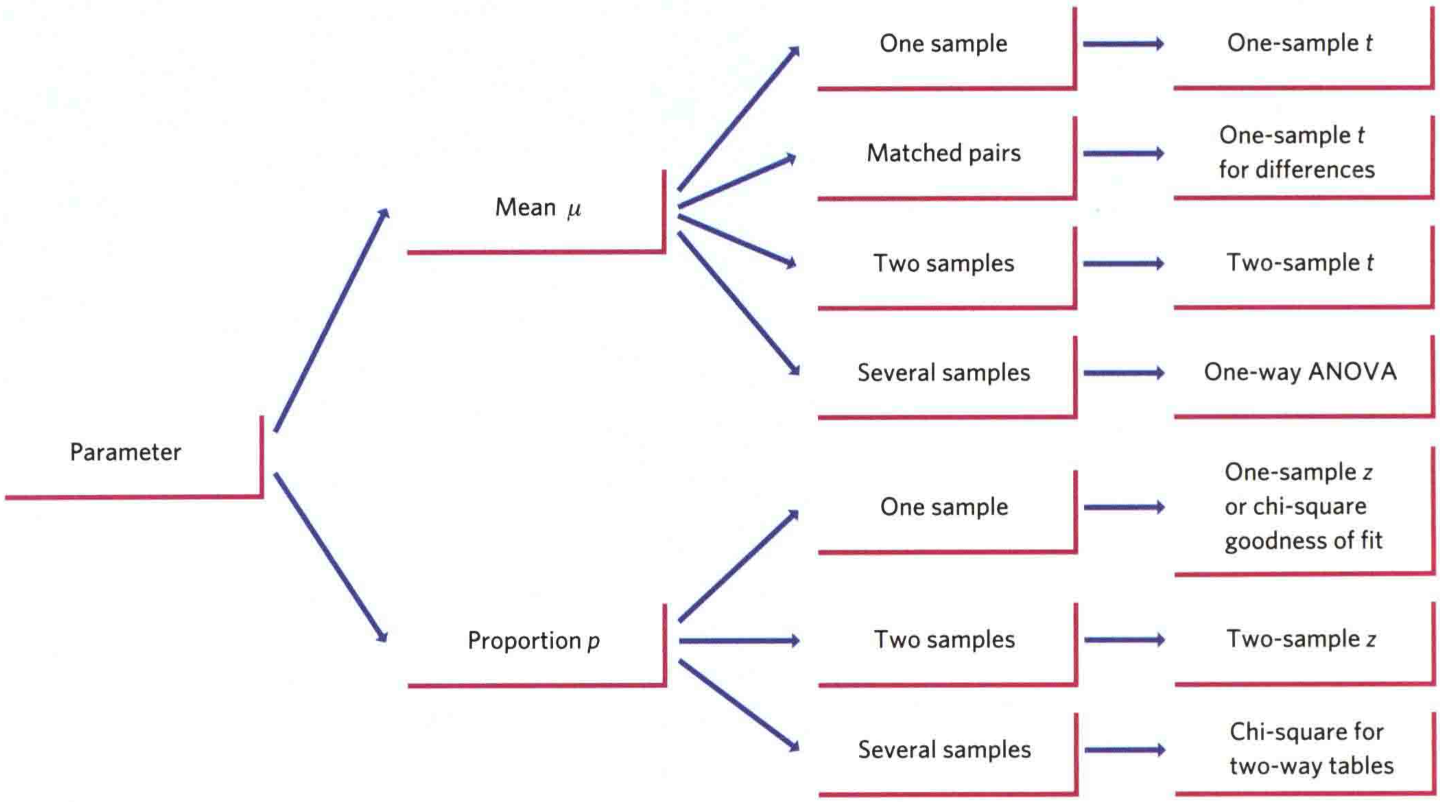
INFERENCE ABOUT MEANS AND PROPORTIONS



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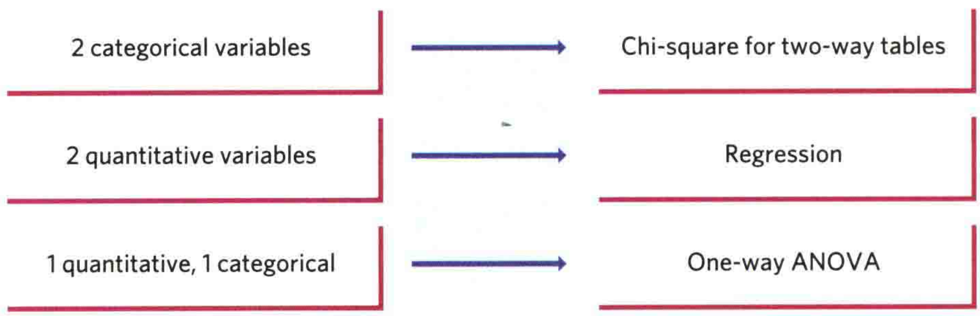

ORGANIZING A STATISTICAL PROBLEM: THE FOUR-STEP PROCESS

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: Make the graphs and carry out the calculations needed 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. Calculate the **confidence interval** or use technology to obtain it.

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 null and alternative hypotheses, and choose the type of test that fits your situation.

SOLVE: Carry out the test in three phases:

1. **Check the conditions** for the test you plan to use.
2. Calculate the **test statistic.**
3. Find the ***P*-value** using a table of Normal probabilities or technology.

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

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The Practice of Statistics in the Life Sciences, third edition (*PSLS 3e*), is an introduction to statistics for college and university students interested in the quantitative analysis of life science problems. Statistics has penetrated the life sciences pervasively with a specific set of application challenges, such as observational studies with confounding variables or experiments with limited sample sizes. Consequently, students can clearly benefit from a teaching of statistics that is explicitly applied to their major. All examples and exercises in *PSLS* are drawn from diverse areas of biology, such as physiology, brain and behavior, epidemiology, health and medicine, nutrition, ecology, and microbiology. 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. The 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 a 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 calculating and graphing.

In the following we describe in further detail for instructors the guiding principles and features of *PSLS 3e*.

GAISE guiding principles

Student audiences and access to technology have changed substantially over the years, and educational guidelines in statistics have evolved accordingly. The American Statistical Association offers a set of recommendations for introductory statistics courses at the college level described in the Guidelines for Assessment and Instruction in Statistics Education (GAISE).[1] The guiding principles of *PSLS 3e* closely follow the six GAISE recommendations for the teaching of introductory statistics.

1. **Emphasize statistical literacy and develop statistical thinking.** Students should understand the basic ideas of statistics, including the need for data, the importance of data production, the omnipresence of variability, and the quantification and explanation of variability. To this end, *PSLS* begins with data analysis (Chapters 1 to 6), then moves to data production (Chapters 7 and 8), and then to probability (Chapters 9 to 13) and inference (Chapters 14 to 28). In studying data analysis, students learn useful skills immediately and get over some of their fear of statistics. Data analysis is a necessary preliminary step to inference in practice, because inference requires suitable data. Designed data production is the surest foundation for inference, and the deliberate use of chance in random sampling and randomized comparative experiments motivates the study of probability in a course that emphasizes data-oriented statistics. *PSLS* gives a full presentation of basic probability and inference (20 of the

28 chapters) but places it in the context of statistics as a whole. Furthering this approach, each chapter contains a summary section titled "This Chapter in Context" that highlights how the concepts from the chapter relate to concepts introduced in earlier chapters and how they will figure in following chapters.

Students should also understand the general statistical approach used to solve scientific problems. A discussion box in Chapter 15 describes this approach in the context of the Nobel Prize-winning discovery of the bacterial origin of most peptic ulcers. The 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. In addition, many of the examples and exercises in *PSLS* are presented in the context of a "four-step process" (State, Plan, Solve, Conclude) intended to teach students how to work on realistic statistical problems. Figure 1 provides an overview. The process emphasizes a major theme in *PSLS*: 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. An icon in the margin helps students see the four-step process as a thread throughout the text. The four-step process appears whenever it fits the statistical content. Its repetitive use should foster the ability to address statistical problems independently.

2. **Use real data.** 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 calculations.

   PSLS 3e provides about 50 examples and exercises per chapter, with both small data sets for in-class use and large data sets (with several variables and a fairly large number of subjects) more suitable for lab work or assignments. Some data sets recur throughout the book, providing an opportunity for comprehensive analysis spanning a range of statistical topics. The wealth of exercises allows instructors to emphasize some statistical topics or biological themes to tailor the content to their specific learning objectives. 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.

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

FIGURE 1 Overview of the "four-step process" used in *PSLS 3e*.

3. **Stress conceptual understanding rather than mere knowledge of procedures.** A first course in statistics introduces many skills, from making a histogram to calculating a correlation to choosing and carrying out a significance test. 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. *PSLS* therefore aims to make clear the larger patterns and big ideas of statistics in the context of learning specific skills and working with specific data. Many of the big ideas are summarized in graphical outlines in Statistics in Summary figures

within the review chapters. Review chapters also offer a comprehensive summary of the important concepts and skills that students should have mastered, along with an opportunity to select the appropriate statistical analysis without the obvious prompting from a chapter title.

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 discusses 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 significance test.

4. **Foster active learning in the classroom.** Learning 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.

   PSLS also provides many examples and exercises, based on small data sets or summary statistics, that can be solved during class with a simple calculator and a table or with a graphing calculator. For courses that include a computer lab component, the large data set exercises at the end of most chapters 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.

   Graphical representations of new concepts can also help students learn through experience. *PSLS* and *BPS* offer on their companion websites a set of interactive applets created to our specifications. These applets are designed primarily to help in learning statistics rather than in doing statistics. We suggest using selected applets for classroom demonstrations even if you do not ask students to work with them. The *Correlation and Regression*, *Confidence Interval*, and *P-value* applets, for example, convey core ideas more clearly than any amount of chalk and talk.

5. **Use technology for developing conceptual understanding and analyzing data.** Automating calculations increases students' ability to complete problems, reduces their frustration, and helps them concentrate on ideas and problem recognition rather than mechanics. *All students should have at least a "two-variable statistics" calculator* with functions for correlation and the least-squares regression line as well as for the mean and standard deviation. Because students have calculators, the text doesn't discuss out-of-date "computing formulas" for the sample standard deviation or the least-squares regression line.

   Many instructors will take advantage of more elaborate technology. And many students will find themselves using statistical software on the job. *PSLS*

- **Tables versus technology.** We asked the *PSLS 3e* reviewers about their use of technology versus printed tables for probability and statistical computations—and found essentially an even split. Some instructors use printed tables in class because technology is not an option for exams, but others use printed tables as a pedagogical preference. Some instructors—in increasing numbers—completely forgo printed tables. Furthering changes initiated in the second edition, *PSLS 3e* uses a modular organization within the relevant chapters that offers instructors the flexibility to teach using either approach.

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 3e*.

Why does the distinction between population and sample not appear in Part I? The concepts of populations and samples are briefly introduced in Chapter 1, but the distinction between them is not emphasized until much later in the book. This is a sign that there is more to statistics than inference. In fact, statistical inference is appropriate only in rather special circumstances. The chapters in Part I present tools and tactics for describing data—any data. Many data sets in these chapters do not lend themselves to inference, because they represent an entire population. John Tukey of Bell Labs and Princeton, the philosopher of modern data analysis, insisted that the population-sample distinction be avoided when it is not relevant, and we agree with him.

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. But in their future employment most students will use statistics mainly in settings other than planned research studies. We place the design of data production (Chapters 7 and 8) after data analysis to emphasize that data-analytic techniques apply to any data. One of the primary purposes of statistical designs for producing data is to make inference possible, so the discussion in Chapters 7 and 8 opens Part II and motivates the study of probability.

Why not delay correlation and regression until late in the course, as is traditional? *PSLS 3e* 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 relations among variables as well as in 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. Inference in the correlation and regression setting is a bit complex, demands software and a close examination of residuals, and often comes right at the end of the course. Delaying all mention of correlation and regression to that point often impedes the mastering of basic uses and properties of these methods. We consider Chapters 3 and 4 (correlation and regression) essential and Chapter 23 (regression inference and residual plots) optional when time constraints limit the amount of material that can be taught. For similar reasons, two-way tables are introduced first in the context of exploratory data analysis before moving on to inference with the chi-square test in Part III.

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 through concrete ways of assigning probabilities 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. What is left with the *optional* Chapters 10 and 12 is mostly "general probability rules" (including conditional probability) and the binomial and Poisson distributions.

We suggest that you omit these optional chapters unless they represent important concepts for your particular audience. 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 med 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.[2] However, attempting to present a substantial introduction to probability in a data-oriented statistics course for students who are not mathematically trained is a very 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, not a question of statistics in practice. Some time in the golden future, we will 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 are going to 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 an SRS, 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.

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On the contrary, starting with inference for p introduces many side issues: no exact Normal sampling distribution, but a Normal approximation to a discrete distribution; use of $\hat{p}$ in both the numerator and the denominator of the test statistic to estimate both the parameter p and $\hat{p}$'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 like Gallup and Pew now report substantially different margins of error (likely accounting for data weighing), making it increasingly challenging to show students real-life applications of the z method for a proportion.

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.[3] 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 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.

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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.

Data files are available in ASCII, Excel, TI, Minitab, SPSS (an IBM Company),[1] and JMP formats.

Student Solutions Manual provides solutions to the odd-numbered exercises in the text. Available electronically within LaunchPad, as well as in print form.

Interactive Table Reader allows students to use statistical tables interactively to seek the information they need.

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[1] SPSS was acquired by IBM in October 2009.

Instructor's Guide with Solutions includes teaching suggestions, chapter comments, and detailed solutions to all exercises. Available electronically within LaunchPad, as well as on the IRCD and in print form.

Test Bank offers hundreds of multiple-choice questions. Also available on CD-ROM (for Windows and Mac), where questions can be downloaded, edited, and resequenced to suit each instructor's needs.

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Additional Resources Available with PSLS3e

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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 10.5, for example, carries no information by itself. But a newborn weighing 10.5 pounds is an indication of a healthy size at birth. 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 make graphs and do calculations. But 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.[1]

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. 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,

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