Roxy Peck / Tom Short

Statistics

Learning from Data

2E

EDITION
2

STATISTICS: LEARNING FROM DATA

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Statistics: Learning from Data,
Second Edition
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To my friends and colleagues

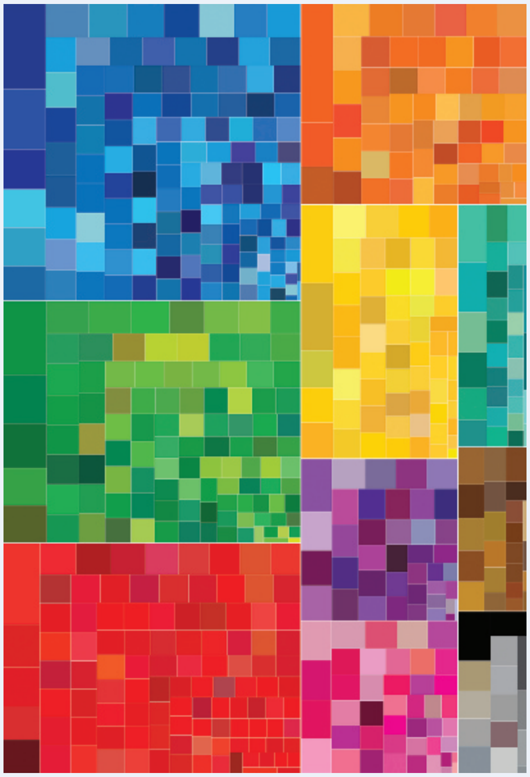
in the Cal Poly Statistics Department

Roxy Peck

To Jerry Moreno and Jerry Senturia for inspiring

me to become a statistician

Tom Short



About the Cover

Artist Nicholas Rougeux used data extracted from the maps of metro systems from around the world to create a graphic image that grouped the colors used to represent the different transit lines into a single image. The sizes of the rectangles that make up the image are based on the number of stations on each transit line. For more information and for an interactive version of this image, see www.c82.net/work/?id=355.

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Preface

Statistics is about learning from data and the role that variability plays in drawing conclusions from data. To be successful, it is not enough for students to master the computational aspects of descriptive and inferential statistics—they must also develop an understanding of the data analysis process at a conceptual level. The second edition of *Statistics: Learning from Data* is informed by careful and intentional thought about how the conceptual and the mechanical should be integrated in order to promote three key types of learning objectives for students:

- conceptual understanding
- mastery of the mechanics
- the ability to demonstrate conceptual understanding and mastery of the mechanics by "putting it into practice"

A Unique Approach

A number of innovative features distinguish this text from other introductory statistics books:

- **A New Approach to Probability**
  There is now quite a bit of research on how students develop an understanding of probability and chance. Using *natural frequencies* to reason about probability, especially conditional probability, is much easier for students to understand. The treatment of probability in this text is complete, including conditional probability and Bayes' Rule type probability calculations, but is done in a way that eliminates the need for the symbolism and formulas that are a roadblock for so many students. For those who also want to provide students with a more traditional coverage, there is an optional new section that introduces probability rules.
- **Chapter on Overview of Statistical Inference (Chapter 7)**
  This short chapter focuses on the things students need to think about in order to select an appropriate method of analysis. In most texts, this is "hidden" in the discussion that occurs when a new method is introduced. Considering this up front in the form of four key questions that need to be answered before choosing an inference method allows students to develop a general framework for inference and makes it easier for students to make correct choices.
- **An Organization That Reflects the Data Analysis Process**
  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. The ordering of topics in the text book mirrors this process: data collection, then data description, then statistical inference.
- **Inference for Proportions Before Inference for Means**
  Inference for proportions is covered before inference for means for the following reasons:
  - This makes it possible to develop the concept of a sampling distribution via simulation, an approach that is more accessible to students than a more formal, theoretical approach. Simulation is simpler in the context of proportions, where it is easy to construct a hypothetical population from which to sample (it is more complicated

to create a hypothetical population in the context of means because this requires making assumptions about shape and spread).

- Large-sample inferential procedures for proportions are based on the normal distribution and don't require the introduction of a new distribution (the *t* distribution). Students can focus on the new concepts of estimation and hypothesis testing without having to grapple at the same time with the introduction of a new probability distribution.

- **Parallel Treatments of Inference Based on Sample Data and Inference Based on Experiment Data**
Many statistical studies involve collecting data from a statistical experiment. The same inference procedures used to estimate or test hypotheses about population parameters also are used to estimate or test hypotheses about treatment effects. However, the necessary assumptions are slightly different (for example, random assignment replaces the assumption of random selection), and the wording of hypotheses and conclusions is also different. Trying to treat both cases together tends to confuse students. This text makes the distinction clear.

New in This Edition

- **New Sections on Randomization-Based Inference Methods**
Research indicates that randomization-based instruction in statistical inference may help learners to better understand the concepts of confidence and significance. The second edition includes new optional sections on randomization-based inference methods. These methods provide alternative analyses that can be used when the conditions required for normal distribution-based inference are not met. Each of the inference chapters (Chapters 9 through 13) now contains a new optional section on randomization-based inference that includes bootstrap methods for simulation-based confidence intervals and randomization tests of hypotheses. These new sections are accompanied by online Shiny apps, which can be used to construct bootstrap confidence intervals and to carry out randomization tests. The App collection that accompanies this text can be found at statistics.cengage.com/Peck2e/Apps.html.
- **Restructured Chapters on Statistical Inference**
The chapters on statistical inference have been restructured to include methods for learning from experiments in the same chapter as methods for learning from samples. While the coverage of inference based on data from statistical experiments (Chapter 14 in the first edition) has been integrated into earlier chapters, the important distinction between inferences based on data from experiments and inferences based on data from sampling is maintained in order to highlight the differences in how hypotheses are worded, in conditions, and in the wording of conclusions in these two situations. The sections of the chapter on inference for two means have also been reordered to put inference for paired samples before inference for independent samples, in order to better connect the paired samples structure with one sample inference for a mean in Chapter 12.
- **Expanded Treatment of Probability**
The second edition contains a new section titled "Calculating Probabilities—A More Formal Approach" for instructors who want to also provide a more traditional coverage of probability. For those who prefer the "hypothetical 1000" approach from the first edition, the newly added traditional section is optional and can be omitted without compromising any of the probability student learning objectives.
- **Updated Examples and Exercises**
In our continuing effort to keep things interesting and relevant, the second edition contains many updated examples and exercises on topics of interest to students that use data from recent journal articles, newspapers, and web posts.

Features That Support Student Engagement and Success

The text also includes a number of features that support conceptual understanding, mastery of mechanics, and putting ideas into practice.

- **Simple Design**
  There is now research showing that many of the "features" in current textbooks are not really helpful to students. In fact, cartoons, sidebars, historical notes, and the like, actually distract students and interfere with learning. The second edition of *Statistics: Learning from Data* has a simple, clean design in order to minimize clutter and maximize student understanding.
- **Chapter Learning Objectives—Keeping Students Informed About Expectations**
  Chapter learning objectives explicitly state the expected student outcomes. Learning objectives fall under three headings: Conceptual Understanding, Mastery of Mechanics, and Putting It into Practice.
- **Preview—Motivation for Learning**
  Each chapter opens with a *Preview* and *Preview Example* that provide motivation for studying the concepts and methods introduced in the chapter. They address why the material is worth learning, provide the conceptual foundation for the methods covered in the chapter, and connect to what the student already knows. A relevant and current example provides a context in which one or more questions are proposed for further investigation. This context is revisited in the chapter once students have the necessary understanding to more fully address the questions posed.
- **Real Data**
  Examples and exercises with overly simple settings do not allow students to practice interpreting results in authentic situations or give students the experience necessary to be able to use statistical methods in real settings. 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.

  Many students are skeptical of the relevance and importance of statistics. Contrived problem situations and artificial data often reinforce this skepticism. Examples and exercises that involve data extracted from journal articles, newspapers, and other published sources and that are of interest to today's students are used to motivate and engage students. Most examples and exercises in the book are of this nature; they cover a very wide range of disciplines and subject areas. These include, but are not limited to, health and fitness, consumer research, psychology and aging, environmental research, law and criminal justice, and entertainment.
- **Exercises Organized into a Developmental Structure—Structuring the Out-of-Class Experience**
  End-of-section exercises are organized into developmental sets. At the end of each section, there are two grouped problem sets. The exercises in each set work together to assess all of the learning objectives for that section. In addition to the two exercise sets, each section also has additional exercises for those who want more practice.

  Answers for the exercises of Exercise Set 1 in each section are included at the end of the book. In addition, many of the exercises in Exercise Set 1 include hints directing the student to a particular example or a relevant discussion that appears in the text. This feature provides direction for students who might need help getting started on a particular exercise. Instructors who prefer that students be more self-directed can assign Exercise Set 2. Answers and hints are not provided for the exercises in Exercise Set 2.
- **Are You Ready to Move On?—Students Test Their Understanding**
  Prior to moving to the next chapter, "Are You Ready to Move On?" exercises allow students to confirm that they have achieved the chapter learning objectives. Like the developmental problem sets of the individual sections, this collection of exercises is developmental in nature. These exercises assess all of the chapter learning objectives and serve as a comprehensive end-of-chapter review.
- **Explorations in Statistical Thinking—Real Data Algorithmic Sampling Exercises and Multivariable Thinking**
  Most chapters contain extended sampling-based, real-data exercises at the end of the chapter. Each student goes online to get a different random sample for the same exercise. These unique exercises are designed to develop conceptual understanding and to teach about sampling variability.

New guidelines from the American Statistical Association recommend that students in the introductory statistics course be provided with opportunities to develop multivariable thinking. To facilitate this, several chapters include an exploration that allows students to work with data sets that include more than two variables.

- **Data Analysis Software**
  JMP data analysis software may be bundled for free with the purchase of a new textbook. See Student Resources for more information.
- **Technology Notes**
  Technology Notes appear at the end of most chapters and give students helpful hints and guidance on completing tasks associated with a particular chapter. The following technologies are included in the notes: JMP, Minitab, SPSS, Microsoft Excel 2007, TI-83/84, and TI-nspire. They include display screens to help students visualize and better understand the steps. More complete technology manuals are also available on the text web site.
- **Chapter Activities—Engaging Students in Hands-On Activities**
  There is a growing body of evidence that students learn best when they are actively engaged. Chapter activities guide students' thinking about important ideas and concepts.
- **Support for Co-Requisite and Pre-Requisite Courses**
  In recognition of the emerging trend of placing students who might previously have been placed into a developmental mathematics sequence directly into the college-level introductory statistics course with co-requisite support, *Statistics Companion: The Math You Need to Know* provides a text companion for the co-requisite course. Also written by Peck and Short, this companion volume provides a just-in-time treatment of the mathematics needed for success in introductory statistics. While *Statistics Companion* can be adapted for use with any introductory statistics text book, it was written specifically with *Statistics: Learning from Data*, Second Edition, in mind and matches the terminology, notation and ordering of topics. The companion can also be adapted for use in a one-semester pre-statistics course for schools that prefer to have students complete their math preparation prior to beginning the statistics course. For more information or to receive a sample copy of *Statistics Companion: The Math You Need to Know*, contact your Cengage Learning Consultant.

Consistent with Recommendations for the Introductory Statistics Course Endorsed by the American Statistical Association

In 2005, the American Statistical Association endorsed the report "College Guidelines in Assessment and Instruction for Statistics Education (GAISE Guidelines)," which included the following six recommendations for the introductory statistics course:

1. Emphasize statistical literacy and develop statistical thinking.
2. Use real data.
3. Stress conceptual understanding rather than mere knowledge of procedures.
4. Foster active learning in the classroom.
5. Use technology for developing conceptual understanding and analyzing data.
6. Use assessments to improve and evaluate student learning.

In 2016, these guidelines were revised. The new guidelines reaffirmed the six recommendations and also included two new recommendations. The two new recommendations were:

- Teach statistics as an investigative process of problem-solving and decision making.
- Give students experience with multivariable thinking.

The second edition of *Statistics: Learning from Data* is consistent with these recommendations and supports the GAISE guidelines in the following ways:

1. **Emphasize Statistical Literacy and Develop Statistical Thinking.**
   Statistical literacy is promoted throughout the text in the many examples and exercises that are drawn from the popular press. In addition, a focus on the role of

variability, consistent use of context, and an emphasis on interpreting and communicating results in context work together to help students develop skills in statistical thinking.

2. **Use Real Data.**
   The examples and exercises are context driven, and the reference sources include the popular press as well as journal articles.
3. **Stress Conceptual Understanding Rather Than Mere Knowledge of Procedures.**
   Nearly all exercises in the text are multipart and ask students to go beyond just calculation, with a focus on interpretation and communication. The examples and explanations are designed to promote conceptual understanding. Hands-on activities in each chapter are also constructed to strengthen conceptual understanding. Which brings us to . . .
4. **Foster Active Learning in the Classroom.**
   While this recommendation speaks more to pedagogy and classroom practice, the second edition of *Statistics: Learning from Data* provides more than 30 hands-on activities in the text and additional activities in the accompanying instructor resources that can be used in class or assigned to be completed outside of class.
5. **Use Technology for Developing Conceptual Understanding and Analyzing Data.**
   The computer has brought incredible statistical power to the desktop of every investigator. The wide availability of statistical computer packages, such as JMP, Minitab, 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, sample output is included throughout the book. In addition, numerous exercises contain data that can easily be analyzed using statistical software. JMP data analysis software can be bundled with new purchases of the text, and technology manuals for JMP and for other software packages, such as Minitab and SPSS, and for the graphing calculator are available in the online materials that accompany this text. The second edition of *Statistics: Learning from Data* also includes a number of Shiny web apps that can be used to illustrate statistical concepts and to implement the simulation-based inference methods covered in new optional sections. The App collection can be found at statistics.cengage.com/Peck2e/Apps.html.
6. **Use Assessments to Improve and Evaluate Student Learning.**
   Comprehensive chapter review exercises that are specifically linked to chapter learning objectives are included at the end of each chapter. In addition, assessment materials in the form of a test bank, quizzes, and chapter exams are available in the instructor resources that accompany this text. The items in the test bank reflect the data-in-context philosophy of the text's exercises and examples.
7. **Teach Statistics as an Investigative Process of Problem-Solving and Decision Making.**
   A systematic approach to inference helps students to see how data are used to answer questions and to learn about the world around them. Without such a foundation, students may see the methods they are learning in their statistics course as just a loose collection of tools and may not develop a real sense of the complete data analysis process. The organization of this text helps to highlight this process, addressing methods of data collection, followed by methods for summarizing data, followed by methods for learning from data. The data analysis process is also featured in Chapter 7, which provides an overview of statistical inference.
8. **Give Students Experience with Multivariable Thinking.**
   Several new explorations have been included in the second edition as part of the Explorations in Statistical Thinking sections. These new explorations provide students with opportunities to work with data sets that include more than one variable in order to develop multivariable thinking.

Instructor and Student Resources

JMP Statistical Software

Access to JMP is free with the purchase of a new book.

JMP is a statistics software for Windows and Macintosh computers from SAS, the market leader in analytics software and services for industry. JMP Student Edition is a streamlined, easy-to-use version that provides all the statistical methods and graphical displays covered in this textbook. Once data is imported, students will find that most procedures require just two or three mouse clicks. JMP can import data from a variety of formats, including Excel and other statistical packages, and you can easily copy and paste graphs and output into documents.

JMP also provides an interface to explore data visually and interactively, which will help your students develop a healthy relationship with their data, work more efficiently with data, and tackle difficult statistical problems more easily. Because its output provides both statistics and graphs together, the student will better see and understand the application of concepts covered in this book as well. JMP Student Edition also contains some unique platforms for student projects, such as mapping and scripting. JMP functions in the same way on both Windows and Mac platforms and instructions contained with this book apply to both platforms.

Access to this software is available for free with new copies of the book and available for purchase standalone at CengageBrain.com or http://www.jmp.com/getse. Find out more at www.jmp.com.

Student Resources

Digital

To access additional course materials and companion resources, please visit www.cengagebrain.com. At the CengageBrain.com home page, search for the ISBN of your title (from the back cover of your book) using the search box at the top of the page. This will take you to the product page where free companion resources can be found.

If your text includes a printed access card, you will have instant access to the following resources:

- Complete step-by-step instructions for JMP, TI-84 Graphing Calculators, Excel, Minitab, and SPSS.
- Data sets in JMP, TI-84, Excel, Minitab, SPSS, SAS, and ASCII file formats.
- Applets used in the Activities found in the text.

Prepare for class with confidence using WebAssign from Cengage *Statistics: Learning from Data*, Second Edition. This online learning platform fuels practice, so you truly absorb what you learn—and are better prepared come test time. Videos and tutorials walk you through concepts and deliver instant feedback and grading, so you always know where you stand in class. Focus your study time and get extra practice where you need it most. Study smarter with WebAssign!

Ask your instructor today how you can get access to WebAssign, or learn about self-study options at www.webassign.com

Print

Student Solutions Manual (ISBN: 9781337558389): Contains fully worked-out solutions to all of the Exercise Set 1 and odd-numbered additional exercises in the text, giving students a way to check their answers and ensure that they took the correct steps to arrive at an answer.

Instructor Resources

Digital

WebAssign from Cengage *Statistics: Learning from Data*, Second Edition, is a fully customizable online solution for STEM disciplines that empowers you to help your students learn, not just do homework. Insightful tools save you time and highlight exactly where your students are struggling. Decide when and what type of help students can access while working on assignments—and incentivize independent work so help features aren't abused. Meanwhile, your students get an engaging experience, instant feedback and better outcomes. A total win-win!

To try a sample assignment, learn about LMS integration or connect with our digital course support, visit http://www.webassign.com/cengage

Instructor Companion Website: Everything you need for your course in one place! Access the Instructor Solutions Manual, full lecture PowerPoints, and other support materials. This collection of book-specific lecture and class tools is available via http://www.cengage.com/login

Instructor Solutions Manual (ISBN: 9781337558396): This guide contains solutions to every exercise in the book. You can download the solutions manual from the Instructor Companion Site.

Print

Teacher's Resource Binder (ISBN: 9781337559263): The Teacher's Resource Binder is full of wonderful resources for both AP Statistics teachers and college professors. These include:

- Recommendations for instructors on how to teach the course, including sample syllabi, pacing guides, and teaching tips.
- Recommendations for what students should read and review for a particular class period or set of class periods.
- Extensive notes on preparing students to take the AP exam.
- Additional examples from published sources (with references), classified by chapter in the text. These examples can be used to enrich your classroom discussions.
- Model responses—examples of responses that can serve as a model for work that would be likely to receive a high mark on the AP exam.
- A collection of data explorations that can be used throughout the year to help students prepare for the types of questions that they may encounter on the investigative task on the AP Statistics Exam.
- Activity worksheets that can be duplicated and used in class.
- A test bank that includes assessment items, quizzes, and chapter exams.

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Roxy Peck and Tom Short

EDITION

2

STATISTICS: LEARNING FROM DATA

1 Collecting Data in Reasonable Ways

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PREVIEW

There is an old saying attributed to statistician Ed Deming, "without data, you are just another person with an opinion." Although anecdotes and coincidences may make for interesting stories, you wouldn't want to make important decisions on the basis of anecdotes alone. For example, just because a friend of a friend ate 16 apricots and then experienced relief from joint pain doesn't mean that this is all you would need to know to help one of your parents choose a treatment for arthritis. Before recommending apricots, you would definitely want to consider relevant data on the effectiveness of apricots as a treatment for arthritis.

Statistical methods help you to make sense of data and gain insight into the world around you. The ability to learn from data is critical for success in your personal and professional life. Data and conclusions based on data are everywhere—in newspapers, magazines, online resources, and professional *publications. But should you believe what you read? For example, should you supplement your diet with black currant oil to stop hair loss? Will playing solitaire for 20 minutes each day help you feel less tired? If you eat proteins before carbohydrates when you eat a meal, will it lower your blood sugar? Should you donate blood twice a year to lower your risk of heart disease? These are just four recommendations out of many that appear in one issue of* **Woman's World (April 4, 2016),** *a magazine with more than 1.3 million readers. In fact, if you followed all of the recommendations in that issue, you would also be loading up on prickly pear oil, hot chocolate, ginger tea, bread, bananas, sweet potatoes, bell peppers, tomatoes, and onions! Some of these recommendations are supported by evidence (data) from research studies, but how reliable is this evidence? Are the conclusions drawn reasonable, and do they apply to you? These important questions will be explored in this chapter.*

CHAPTER LEARNING OBJECTIVES

Conceptual Understanding

After completing this chapter, you should be able to

C1 Understand the difference between an observational study and an experiment.
C2 Understand that the conclusions that can be drawn from a statistical study depend on the way in which the data are collected.
C3 Explain the difference between a census and a sample.
C4 Explain the difference between a statistic and a population characteristic.
C5 Understand why random selection is an important component of a sampling plan.
C6 Understand why random assignment is important when collecting data in an experiment.
C7 Understand the difference between random selection and random assignment.
C8 Explain why volunteer response samples and convenience samples are unlikely to produce reliable information about a population.
C9 Understand the limitations of using volunteers as subjects in an experiment.
C10 Explain the purpose of a control group in an experiment.
C11 Explain the purpose of blinding in an experiment.

Mastering the Mechanics

After completing this chapter, you should be able to

M1 Create a sampling plan that could produce a simple random sample from a given population.
M2 Describe a procedure for randomly assigning experimental units to experimental conditions (for example, subjects to treatments) given a description of an experiment, the experimental conditions, and the experimental units.

Putting It into Practice

After completing this chapter, you should be able to

P1 Distinguish between an observational study and an experiment.
P2 Evaluate the design of an observational study.
P3 Evaluate the design of a simple comparative experiment.
P4 Evaluate whether conclusions drawn from a study are appropriate, given a description of the statistical study.

SECTION 1.1 Statistics—It's All About Variability

Statistical methods allow you to collect, describe, analyze, and draw conclusions from data. If you lived in a world where all measurements were identical for every individual, these tasks would be simple. For example, consider a population consisting of all of the students at a college. Suppose that every student is enrolled in the same number of courses, spent exactly the same amount of money on textbooks, and favors increasing student fees to support expanding library services. For this population, there is no variability in number of courses, amount spent on books, or student opinion on the fee increase. A person studying students from this population to draw conclusions about any of these three variables would have an easy task. It would not matter how many students were studied or how the students were selected. In fact, you could collect information on the number of courses, amount spent on books, and opinion on the fee increase by just stopping the next student who happened to walk by the library. Because there is no variability in the population, this one individual would provide complete and accurate information about the population, and you could draw conclusions with no risk of error.

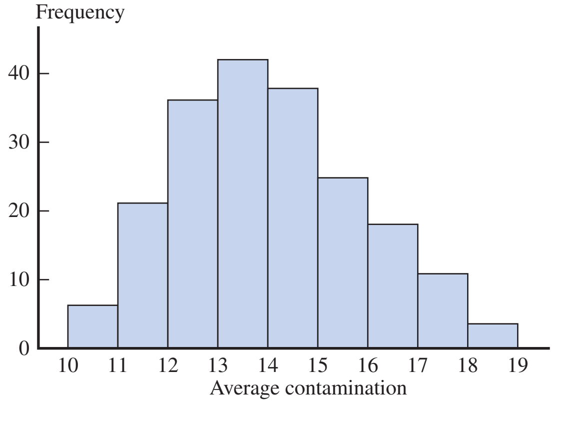
The situation just described is obviously unrealistic. Populations with no variability are exceedingly rare, and they are of little statistical interest because they present no challenge. In fact, variability is almost universal. It is variability that makes life interesting. To be able to collect, describe, analyze, and draw conclusions from data in a sensible way, you need to develop an understanding of variability.

The following example illustrates how describing and understanding variability provide the foundation for learning from data.

Example 1.1 Monitoring Water Quality

As part of its regular water quality monitoring efforts, an environmental control board selects five water specimens from a particular well each day. The concentration of contaminants in parts per million (ppm) is measured for each of the five specimens, and then the average of the five measurements is calculated. The graph in Figure 1.1 is an example of a histogram. (You will learn how to construct and interpret histograms in Chapter 2.) This histogram summarizes the average contamination values for 200 days.

FIGURE 1.1 Histogram of average contamination



Suppose that a chemical spill has occurred at a manufacturing plant 1 mile from the well. It is not known whether a spill of this nature would contaminate groundwater in the area of the spill and, if so, whether a spill this distance from the well would affect the quality of well water.

One month after the spill, five water specimens are collected from the well, and the average contamination is 15.5 ppm. Considering the variation before the spill shown in the histogram, would you interpret this as evidence that the well water was affected by the spill? What if the calculated average was 17.4 ppm? How about 22.0 ppm?

Before the spill, the average contaminant concentration varied from day to day. An average of 15.5 ppm would not have been an unusual value, so seeing an average of 15.5 ppm after the spill isn't necessarily an indication that contamination has increased. On the other hand, an average as large as 17.4 ppm is less common, and an average as large as 22.0 ppm is not at all typical of the pre-spill values. In this case, you would probably conclude that the well contamination level has increased.

Reaching a conclusion requires an understanding of variability. Understanding variability allows you to distinguish between usual and unusual values. The ability to recognize unusual values in the presence of variability is an important aspect of many statistical methods and is also what enables you to quantify the chance of being incorrect when a conclusion is based on available data.

SECTION 1.2 Statistical Studies: Observation and Experimentation

If the goal is to make good decisions based on data, it should come as no surprise that the way you obtain the data is very important. It is also important to know what questions you hope to answer with data. Depending on what you want to learn, two types of statistical studies are common—*observational studies* and *experiments*.

Sometimes you are interested in answering questions about characteristics of a single **population** or in comparing two or more well-defined populations. To accomplish this, you select a **sample** from each population and use information from the samples to learn about characteristics of the populations.

DEFINITION

Population: The population is the entire collection of individuals or objects that you want to learn about.

Sample: A sample is a part of the population that is selected for study.

For example, many people, including the author of **"The 'CSI Effect': Does It Really Exist?" (*National Institute of Justice* [2008]: 1–7)**, have speculated that watching crime scene investigation TV shows (such as *CSI*, *Cold Case*, *Bones*, or *Numb3rs*) may be associated with the kind of high-tech evidence that jurors expect to see in criminal trials. Do people who watch such shows on a regular basis have higher expectations than those who do not watch them? To answer this question, you would want to learn about two populations, one consisting of people who watch crime scene investigation shows on a regular basis and the other consisting of people who do not. You could select a sample of people from each population and interview these people to determine their levels of expectation for high-tech evidence in a criminal case. This would be an example of an **observational study**. In an observational study, it is important to obtain samples that are representative of the corresponding populations.

Sometimes the questions you are trying to answer cannot be answered using data from an observational study. Such questions are often of the form, "What happens when …?" or "What is the effect of …?" For example, a teacher may wonder what happens to student test scores if the lab time for a chemistry course is increased from 3 hours to 6 hours per week. To answer this question, she could conduct an **experiment**. In such an experiment, the value of a *response* (test score) would be recorded under different *experimental conditions* (3-hour lab and 6-hour lab). The person carrying out the experiment creates the experimental conditions and also determines which people will be assigned to each experimental condition.

DEFINITION

An **observational study** is a study in which the person conducting the study observes characteristics of a sample selected from one or more existing populations. The goal of an observational study is to use data from the sample to learn about the corresponding population. In an observational study, it is important to obtain a sample that is representative of the population.

An **experiment** is a study in which the person conducting the study considers how a response behaves under different experimental conditions. The person carrying out the study determines who will be in each experimental group and what the experimental conditions will be. In an experiment, it is important to have comparable experimental groups.

Observational studies and experiments can both be used to compare groups. In an observational study, the person carrying out the study does not control who is in which population. However, in an experiment, the person conducting the study *does* control who is in which experimental group. For example, in the observational study to compare expectations of those who watch crime scene investigation shows and those who do not, the person conducting the study does not determine which people will watch crime scene investigation shows. However, in the chemistry experiment, the person conducting the study *does* determine which students will be in the 3-hour lab group and which students will be in the 6-hour lab group. This seemingly small difference is critical when it comes to drawing conclusions from a statistical study. This is why it is important to determine whether data are from an observational study or from an experiment. We will return to this important distinction in Section 1.5.

The following two examples illustrate how to determine whether a study is an observational study or an experiment.

Example 1.2 Chew More, Eat Less?

The article **"Increasing the Number of Chews before Swallowing Reduces Meal Size in Normal-Weight, Overweight and Obese Adults" (*Journal of the Academy of Nutrition and Dietetics* [2014]: 926–931)** describes a study that investigated whether chewing each bite of food more before swallowing would result in people eating less. Participants in the study were adults between the ages of 18 to 45 years. At the beginning of the study, each participant was observed as they ate five pizza rolls, and the number of chews made before swallowing was observed to determine a baseline for that participant.

Participants were then invited back for a second session on a different day. They were asked to eat their usual breakfast on that day and to not eat anything after breakfast. At the second session, the participants were assigned to one of three groups. All participants were provided with a platter of pizza rolls and were told to eat until they were comfortably full. They were also told they could request more pizza rolls if they wanted more. Each participant was also told how many times to chew each pizza roll before swallowing. The participants in group 1 were given a number of chews equal to their baselines. The participants in group 2 were given a number of chews that was 150% of (one and a half times as large as) their baselines. The participants in group 3 were given a number of chews that was 200% of (twice as large as) their baselines.

After analyzing data from this study, the researcher concluded that people ate about 10% less when they increased the number of chews by 50% (group 2) and about 15% less when they doubled the number of chews (group 3).

Is this study an observational study or an experiment? To answer this question, you need to consider how the three groups in the study were formed. Because the study participants were assigned to one of the three groups by the researchers conducting the study, the study is an experiment. As you will see in Section 1.4, the way the researchers decide which people go into each group is an important aspect of the study design.

Example 1.3 Caffeine and Sleep

The article **"Adolescents Living the 24/7 Lifestyle: Effects of Caffeine and Technology on Sleep Duration and Daytime Functioning" (*Pediatrics* [2009]: e1005–e1010)** describes a study in which researchers investigated whether there is a relationship between amount of sleep and caffeine consumption. They found that teenagers who usually get less than 8 hours of sleep on school nights were more likely to report falling asleep during school and consume more caffeine on average than teenagers who usually get 8 to 10 hours of sleep on school nights.

In the study described, two populations of teenagers were compared—teenagers who usually get less than 8 hours of sleep on school nights and teenagers who usually get 8 to 10 hours of sleep on school nights. Did the researchers determine which teenagers were in each group? The researchers had no control over how long the study participants slept, so the study is an observational study and not an experiment. It is still possible to make reasonable comparisons between the two populations, as long as the groups of teenagers in the study were chosen to be representative of the two populations of interest—*all* teenagers who usually get less than 8 hours of sleep on school nights and *all* teenagers who usually get 8 to 10 hours of sleep on school nights. The way in which the teenagers in the two study groups were chosen is an important aspect of the design of this observational study.

In the next sections, the design of observational studies and experiments will be considered in more detail.

Summing It Up—Section 1.2

The following learning objectives were addressed in this section:

Conceptual Understanding

C1: Understand the difference between an observational study and an experiment.

An **observational study** is a study in which the person conducting the study observes characteristics of a sample selected from a population. The goal of an observational study is to learn about a population.

An **experiment** is a study in which the person conducting the study considers how a response behaves under different experimental conditions. The person carrying out the study determines who will be in each experimental group.

Putting It into Practice

P1: Distinguish between an observational study and an experiment.

Once you understand the difference between an observational study and an experiment, if you are given a description of a study, you should be able to determine if it is an observational study or an experiment. See Examples 1.2 and 1.3.

SECTION 1.2 EXERCISES

Each Exercise Set assesses the following chapter learning objectives: C1, P1

SECTION 1.2 Exercise Set 1

For each of the statistical studies described in Exercises 1.1 to 1.5, indicate whether the study is an observational study or an experiment. Give a brief explanation for your choice. (Hint: See Examples 1.2 and 1.3.)

1.1 The following conclusion from a statistical study appeared in the article **"Smartphone Nation" (*AARP Bulletin*, September 2009)**: "If you love your smartphone, you're far from alone. Half of all boomers sleep with their cell phone within arm's length. Two of three people ages 50 to 64 use a cell phone to take photos, according to a 2010 Pew Research Center report."

1.2 The press release **"Men Need to Man Up, According to Ball Park Brand Survey" (*PR Newswire*, October 14, 2015)** describes the results of a study in which 1012 U.S. men were asked a number of questions about "life's tough conversations." One result from this survey was summarized in a ***USA TODAY Snapshot*** **(*USA TODAY*, November 6, 2015)** that said that "nearly 1 in 5 men would pay someone to handle their breakup for them."

1.3 An article in ***USA TODAY*** **(October 19, 2010)** describes a study of how young children learn. Sixty-four 18-month-old toddlers participated in the study. The toddlers were allowed to play in a lab equipped with toys, which also had a robot hidden behind a screen. The article states: "After allowing the infants play time, the team removed the screen and let the children see the robot. In some tests, an adult talked to the robot and played with it. In others the adult ignored the robot. After the adult left the room, the robot beeped and then turned its head to look at a toy to the side of the infant. In cases where the adult had played with the robot, the infant was four times more likely to follow the robot's gaze to the toy."

1.4 In a survey of 2500 U.S. adults, 69% responded that they were confident that "smart homes" will be a commonplace as smartphones within 10 years **(*Intel Survey: Architecting the Future of the Smart Home 2025*, [2015]: download.intel.com/newsroom/kits/iot/pdfs/IntelSmartHomeSurveyBackgrounder.pdf, retrieved September 25, 2016).**

1.5 A paper appearing in ***The Journal of Pain*** **(March 2010, 199–209)** described a study to determine if meditation has an effect on sensitivity to pain. Study participants were assigned to one of three groups. One group meditated for 20 minutes; one group performed a distraction task (working math problems!) for 20 minutes; and one group practiced a relaxation technique for 20 minutes. Sensitivity to pain was measured both before and after the 20-minute session.

SECTION 1.2 Exercise Set 2

For each of the statistical studies described in Exercises 1.6–1.10, indicate whether the study is an observational study or an experiment. Give a brief explanation for your choice.

1.6 A news release from Intel titled **"Intel's Security International Internet of Things Smart Home Survey Shows Many Respondents Sharing Personal Data for Money" (March 30, 2016, newsroom.intel.com/news-releases/intel-securitys-international-internet-of-things-smart-home-survey/, retrieved September 25, 2016)** described a survey conducted in 2015. The news release states "A total of 9,000 consumers were interviewed globally, including 2,500 from the United States, 1,000 from the United Kingdom, 1,000 from France, 1,000 from Germany, 1,000 from Brazil, 1,000 from India, 500 from Canada, 500 from Mexico and 500 from Australia." Among the findings from the survey were that 54% of the respondents worldwide would be willing to share personal data collected from devices in their homes with companies in exchange for money.

1.7 The paper **"Health Halos and Fast-Food Consumption" (*Journal of Consumer Research* [2007]: 301–314)** described a study in which 46 college students volunteered to participate. Half of the students were given a coupon for a McDonald's Big Mac sandwich and the other half were given a coupon for a Subway 12-inch Italian BMT sandwich. (For comparison, the Big Mac has 600 calories, and the Subway 12-inch Italian BMT sandwich has 900 calories.) The researchers were interested in how the perception of Subway as a healthy fast-food choice and McDonald's as an unhealthy fast-food choice would influence what additional items students would order with the sandwich. The researchers found that those who received the Subway coupon were less likely to order a diet soft drink, more likely to order a larger size drink, and more likely to order cookies than those who received the Big Mac coupon.

1.8 ***USA TODAY*** **(August 25, 2015)** reported that "American women favor Kate Middleton as a shopping buddy over Michelle Obama by 10 percentage points." This statement was based on a study in which 1001 adults were surveyed about their shopping preferences.

1.9 In a study of whether taking a garlic supplement reduces the risk of getting a cold, 146 participants were assigned to either a garlic supplement group or to a group that did not take a garlic supplement **("Garlic for the Common Cold," Cochrane Database of Systematic Reviews, 2009)**. Based on the study, it was concluded that the proportion of people taking a garlic supplement who get a cold is lower than the proportion of those not taking a garlic supplement who get a cold.

1.10 The article **"Baby Scientists Experiment with Everything" (*The Wall Street Journal*, April 18, 2015)** describes a series of studies published in the journal *Science*. In one of these studies, 11-month old children were assigned to one of two groups. The children in one group were shown a ball behaving as expected, such as rolling into a wall or falling off an edge. The children in the other group were shown a ball behaving in an unexpected way, such as rolling through what appeared to be a solid wall or rolling off an edge and remaining suspended in the air. The children were then given a ball and another toy. The researchers found that the children in the group that saw the ball behaving as expected showed no preference for the ball over the other toy, but that the children who saw the ball behaving in an unexpected way tended to choose the ball, and that they also played with it differently and tested the ball's behavior by dropping it or rolling it.

ADDITIONAL EXERCISES

1.11 The article **"How Dangerous Is a Day in the Hospital?" (*Medical Care* [2011]: 1068–1075)** describes a study to determine if the risk of an infection is related to the length of a hospital stay. The researchers looked at a large number of hospitalized patients and compared the proportions who got an infection for two groups of patients—those who were hospitalized overnight and those who were hospitalized for more than one night. Indicate whether the study is an observational study or an experiment. Give a brief explanation for your choice.

1.12 The authors of the paper **"Fudging the Numbers: Distributing Chocolate Influences Student Evaluations of an Undergraduate Course" (*Teaching in Psychology* [2007]: 245–247)** carried out a study to see if events unrelated to an undergraduate course could affect student evaluations. Students enrolled in statistics courses taught by the same instructor participated in the study. All students attended the same lectures and one of six discussion sections that met once a week. At the end of the course, the researchers chose three of the discussion sections to be the "chocolate group." Students in these three sections were offered chocolate prior to having them fill out course evaluations. Students in the other three sections were not offered chocolate. The researchers concluded that "Overall, students offered chocolate gave more positive evaluations than students not offered chocolate." Indicate whether the study is an observational study or an experiment. Give a brief explanation for your choice.

1.13 The article **"Why We Fall for This" (*AARP Magazine*, May/June 2011)** described a study in which a business professor divided his class into two groups. He showed students a mug and then asked students in one of the groups how much they would pay for the mug. Students in the other group were asked how much they would sell the mug for if it belonged to them. Surprisingly, the average values assigned to the mug were quite different for the two groups! Indicate whether the study is an observational study or an experiment. Give a brief explanation for your choice.

1.14 The same article referenced in Exercise 1.13 also described a study which concluded that people tend to respond differently to the following questions:

Question 1: Would you rather have $50 today or $52 in a week?

Question 2: Imagine that you could have $52 in a week. Would you rather have $50 now?

The article attributes this to the question wording: the second question is worded in a way that makes you feel that you are "losing" $2 if you take the money now. Do you think that the study which led to the conclusion that people respond differently to these two questions was an observational study or an experiment? Explain why you think this.

SECTION 1.3 Collecting Data: Planning an Observational Study

In Section 1.2, two types of statistical studies were described—observational studies and experiments. In this section, you will look at some important considerations when planning an observational study or when deciding whether an observational study performed by others was well planned.

Planning an Observational Study—Collecting Data by Sampling

The purpose of an observational study is to collect data that will allow you to learn about a single population or about how two or more populations might differ. For example, you might want to answer the following questions about students at a college:

What proportion of the students at the college support a proposed student fee for improved recreational facilities?

What is the average number of hours per month that students at the college devote to community service?

In each case, the population of interest is all students at the college. The "ideal" study would involve carrying out a **census** of the population. A census collects data from everyone in the population, so that every student at the college would be included in the study. If you were to ask every student whether he or she supported the fee or how many hours per month he or she devotes to community service, you would be able to easily answer the questions above.

Unfortunately, very few observational studies involve a census of the population. It is usually not practical to get data from every individual in the population of interest. Instead, data are obtained from just a part of the population, called a sample. Then **statistics** calculated from the sample are used to answer questions about **population characteristics**.