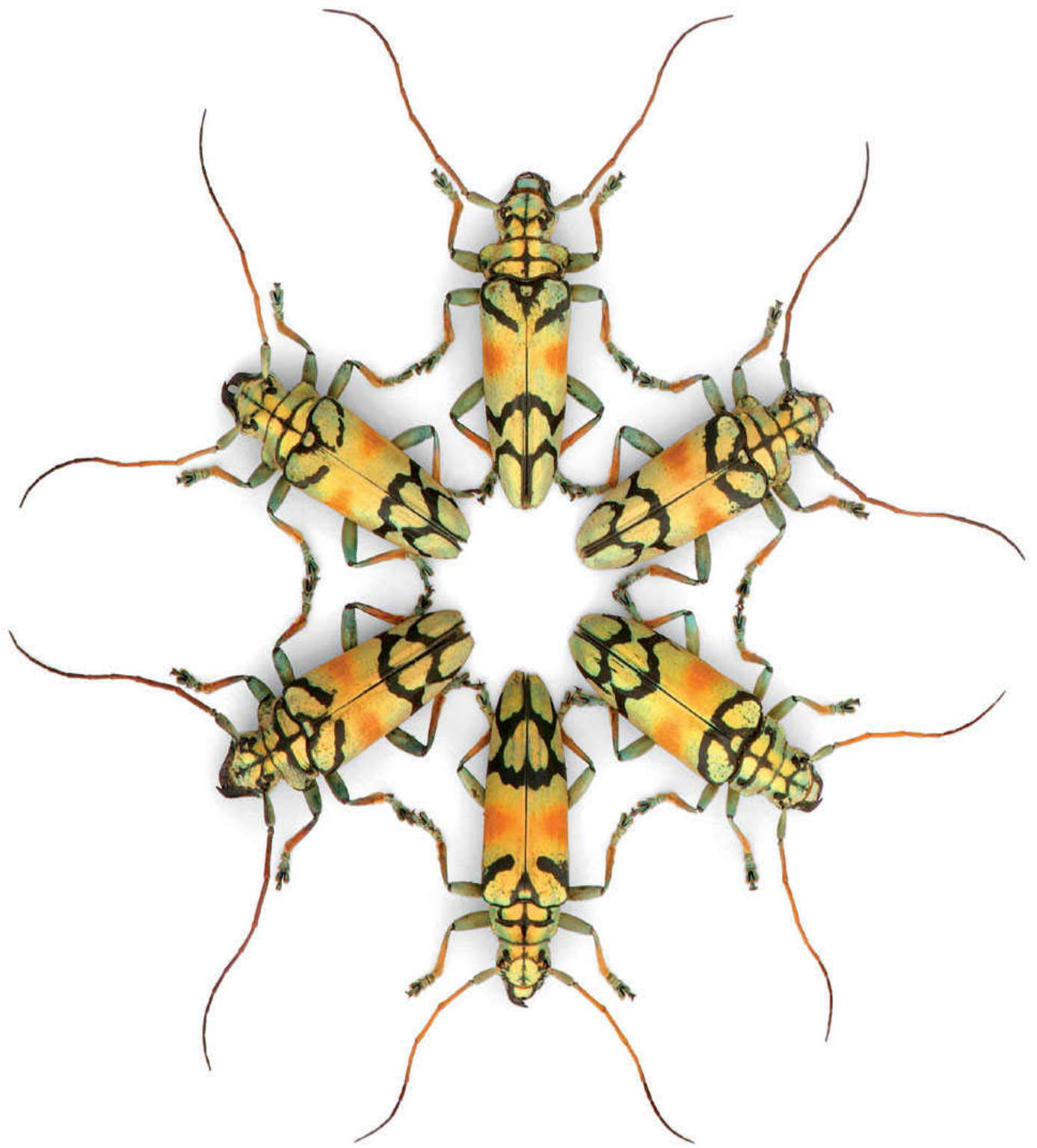


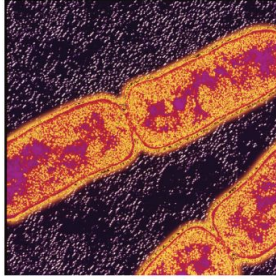


The Analysis of Biological Data

WHITLOCK · SCHLUTER

THIRD EDITION

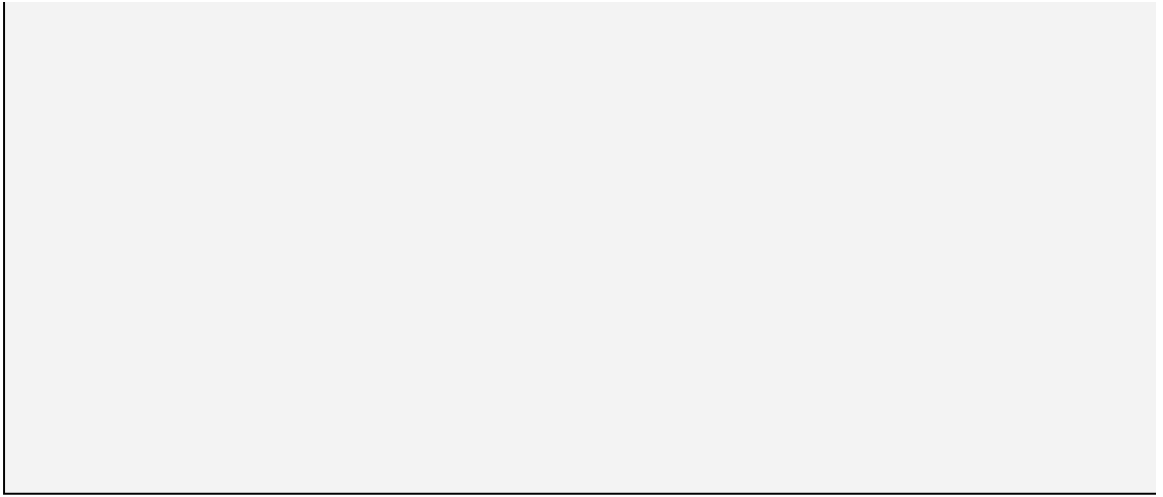
The Analysis of Biological Data



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Description

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The Analysis of Biological Data

Third Edition

Michael C. Whitlock and Dolph Schluter



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To Sally and Wilson, Andrea and Maggie

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Preface

Modern biologists need the powerful tools of data analysis. As a result, an increasing number of universities offer, or even require, a basic data analysis course for all their biology and premedical students. We have been teaching such a course at the University of British Columbia for the last three decades. Over this period, we have sought a textbook that covered the material we needed in an introductory course at just the right level. We found that most texts were too technical and encyclopedic, or else they didn't go far enough, missing methods that were crucial to the practice of modern biology and medicine. We wanted a book that had a strong emphasis on intuitive understanding to convey meaning, rather than an overreliance on formulas. We wanted to teach by example, and the examples needed to be interesting. Most importantly, we needed a biology book, addressing topics important to biologists and health care providers handling real data.

We couldn't find the book that we needed, so we decided to write this one to fill the gap. We include several unusual features that we have discovered to be helpful for effectively reaching our audience:

Interesting biology examples and exercise sets.

Our teaching has shown us that biology students learn data analysis best in the context of interesting examples drawn from the medical and biological literature. Statistics is a means to an end, a tool to learn about the human and natural world. By emphasizing what we

can learn about the science, the power and value of statistics becomes plain. Plus, it's just more fun for everyone concerned.

Every chapter has several biological or medical examples of key concepts, and each example is prefaced by a substantial description of the biological setting. The examples are illustrated with photos of the real organisms, so that students can look at what they're learning about. The emphasis on real and interesting examples carries into the problem sets; each chapter has many questions based on real data about biological and medical issues. These include Calculation Practice Problems that take the student step-by-step through the important procedures described in the chapter. Two or three such problems are at the start of most of the chapter problem sets. We include three sections of review problems (after [Chapters 9](#), [13](#), and [17](#)) to allow cumulative review of the important concepts up to that point in the book. In this third edition, we have added dozens of new problems.

Intuitive explanations of key concepts.

Statistical reasoning requires a lot of new ways of thinking. Students can get lost in the barrage of new jargon and multitudinous tests. We have found that starting from an intuitive foundation, away from all the details, is extremely valuable. We take an intuitive approach to basic questions: What's a good sample? What's a confidence interval? Why do an experiment? The first several chapters establish this basic knowledge, and the rest of the book builds on it.

Practical data analysis.

As its title suggests, this book focuses on data rather than the mathematical foundations of statistics. We teach how to make good graphical displays, and we emphasize that a good graph is the beginning point of any good data analysis. We give equal time to estimation and hypothesis testing, and we avoid treating the P-value *P-value* as an end in itself. The book does not demand a knowledge of mathematics beyond simple algebra. We focus on practicality over nuance, on biological usefulness over theoretical hand wringing. We not only teach the “right” way of doing something but also highlight some of the pitfalls that might be encountered.

We demonstrate how to carry out the calculations for most methods so that the steps are not mysterious to students. At the same time, we know that a computer will be available for most calculations. Hence, we focus on the concepts of biological data analysis and how statistics can help extract scientific insight from data. With the power of modern computers at hand, the challenge in analyzing data becomes knowing what method to use and why.¹ We imagine and hope that every course using this book will have a component encouraging students to use computer statistical packages. The diversity of such packages is immense, and so we have not tied the book to any particular program. Nevertheless, many biologists and users of this book analyze data with the R statistical computing package. Accordingly, we provide R scripts for all the examples in this book at the book’s web site (whitlockschluter3e.zoology.ubc.ca). This site also includes a series of self-guided labs to teach students

the basics of using R at a reasonable pace, and in an order that matches the presentation of the concepts in the book.

Practical experimental design.

A biologist cannot do good statistics—or good science—without a practical understanding of experimental design. Unlike most books, our book covers basic topics in experimental design, such as controls, randomization, pseudoreplication, and blocking, and we do it in a practical, intuitive way.

Coverage of modern topics.

Modern biology uses a larger toolkit than the one available a generation ago. In this book, we go beyond most introductory books by establishing the conceptual principles of important topics such as likelihood, non-linear regression, permutation tests, survival analysis, and the bootstrap.

Useful summaries.

Near the end of each chapter is a short, clear summary of the key concepts, and most chapters end with Quick Formula Summaries that put most equations in one easy-to-find place.

Interleaves.

Between chapters are short essays that we call interleaves. These interleaves cover a variety of conceptual topics in a nontechnical way—ideas that are nevertheless crucial for the interpretation of statistical results in scientific research. Several of them focus on

common mistakes in the analysis and interpretation of biological data and how to avoid them. Although the interleaves are pressed between the chapters, they complement the material in the core chapters in important ways. We believe that the interleaves discuss some of the most important topics of the book, such as the difference between correlation and causation (Interleaf 1), the meaning of statistical significance (Interleaf 3), why control treatments are necessary (Interleaf 6), and the distortions caused by publication bias (Interleaf 10). Interleaf 7 summarizes what statistical test should be used and when, and it is a good place to start when reviewing for exams.

We think *The Analysis of Biological Data* provides a good background in data analysis for biologists and medical practitioners, covering a broad range of topics in a practical and intuitive way. It works for our classes; we hope that it works for yours, too.

Organization of the book

The Analysis of Biological Data is divided into five parts, each with a handful of chapters as indicated in the table of contents. We recommend starting with the first part, because it introduces many basic concepts that are used throughout the book, such as sampling, drawing a good graph, describing data, estimating, hypothesis testing, and concepts in probability. These early chapters are meant to be read in their entirety.

After the first block, most chapters progress from the most general topics at the start to more specialized topics by the end. Each chapter

is structured so that a basic understanding of the topic may be obtained from the earliest sections. For example, in the chapter on analysis of variance ([Chapter 15](#)), the basics are taught in the first two sections; reading [Sections 15.1](#) and [15.2](#) gives roughly the same material that most introductory statistics texts provide about this method. [Sections 15.3–15.6](#) explain additional twists and other interesting applications.

The last block of chapters ([Chapters 18–21](#)) is mainly for the adventurous and the curious. These chapters introduce topics, such as likelihood, bootstrapping, and a brand-new chapter on survival analysis ([Chapter 21](#)), that are commonly encountered in the biological and medical literature but not often mentioned in an introductory course. These chapters introduce the basic principles of each topic, discuss how the methods work, and point to where you might look to find out more.

A basic course could be taught by using only [Chapters 1–17](#) and, within this subset of chapters, by stopping after [Sections 5.8](#), [7.3](#), [8.4](#), [9.4](#), [12.6](#), [13.6](#), [15.2](#), [16.4](#), and [17.6](#) in their respective chapters. We suggest that all courses highlight specific topics covered only in the interleaves.

Each chapter ends with a series of problems that are designed to test students' understanding of the concepts and the practical application of statistics. The problems are divided into Practice Problems and Assignment Problems. Short answers to all Practice Problems and Review Problems are provided in the back of the book; answers to

the Assignment Problems are available to instructors only from the publisher. For a copy, please send an email to DL-WhitlockSchluter3e@macmillan.com. Other teaching resources for the book are available online at whitlockschluter3e.zoology.ubc.ca.

A word about the data

The data used in this book are real, with a few well-marked exceptions. For the most part, these data were obtained directly from published papers. In some cases, we contacted the authors of articles who generously provided the raw data for our use. Often, when raw data were not provided in the original paper, we resorted to obtaining data points by digitizing graphical depictions, such as scatter plots and histograms. Inevitably, the numbers we extracted differ slightly from the original numbers because of measurement error. In rare cases, we generated data by computer that matched the statistical summaries in the paper. In all cases, the results we present are consistent with the conclusions of the original papers. Most of the data sets are available online at whitlockschluter3e.zoology.ubc.ca.

About the authors

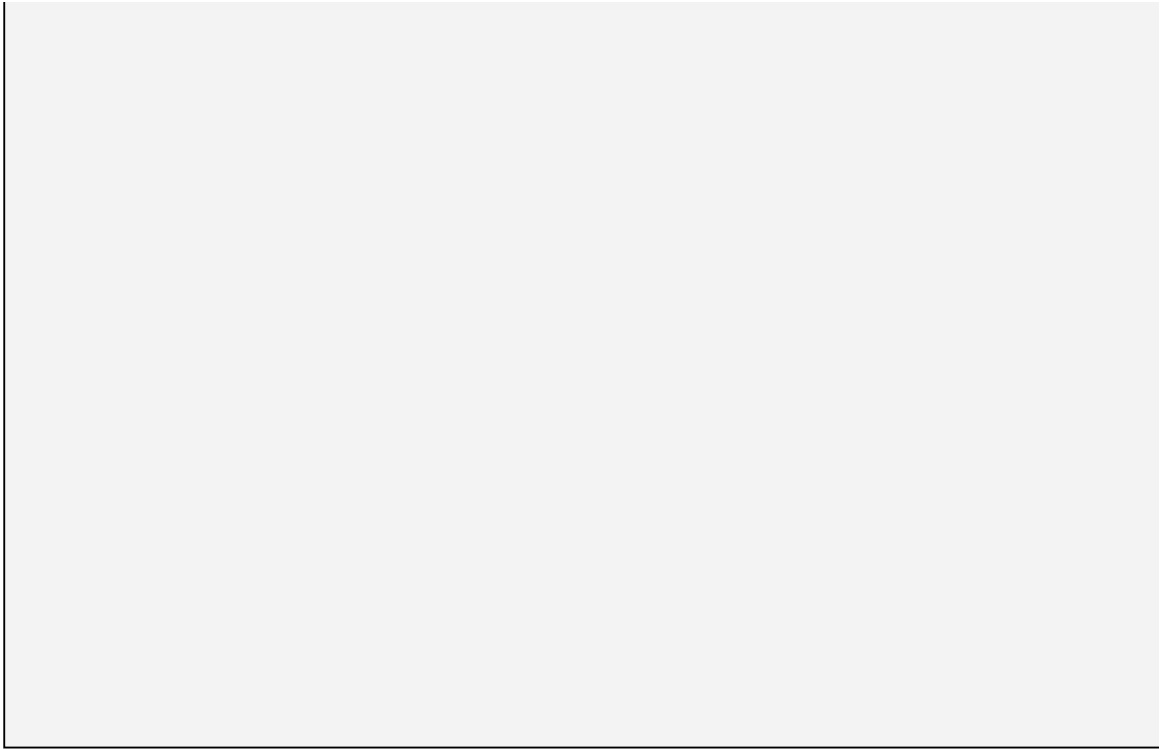
Michael Whitlock is an evolutionary biologist and population geneticist. He is a professor of zoology at the University of British Columbia, where he has taught statistics to biology students since 1995. Whitlock is known for his work on the spatial structure of biological populations, genetic drift, and the genetics of adaptation. He has worked with fungus beetles, rhinos, and fruit flies; mathematical theory; and statistical genetics. He is a member of the American Academy of Arts and Sciences and a Fellow of the Royal Society of Canada. He has been editor-in-chief of *The American Naturalist* and on the editorial boards of nine scientific journals.

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Description

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We owe a debt to the students of BIOL 300 at the University of British Columbia, who class-tested this book over the last several years. The book also benefited by class testing at several colleges and universities. George Gilchrist and his students gave us a very detailed and extremely helpful set of comments at a crucial stage of the book.

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name at whitlockschluter3e.zoology.ubc.ca/acknowledgments.html.

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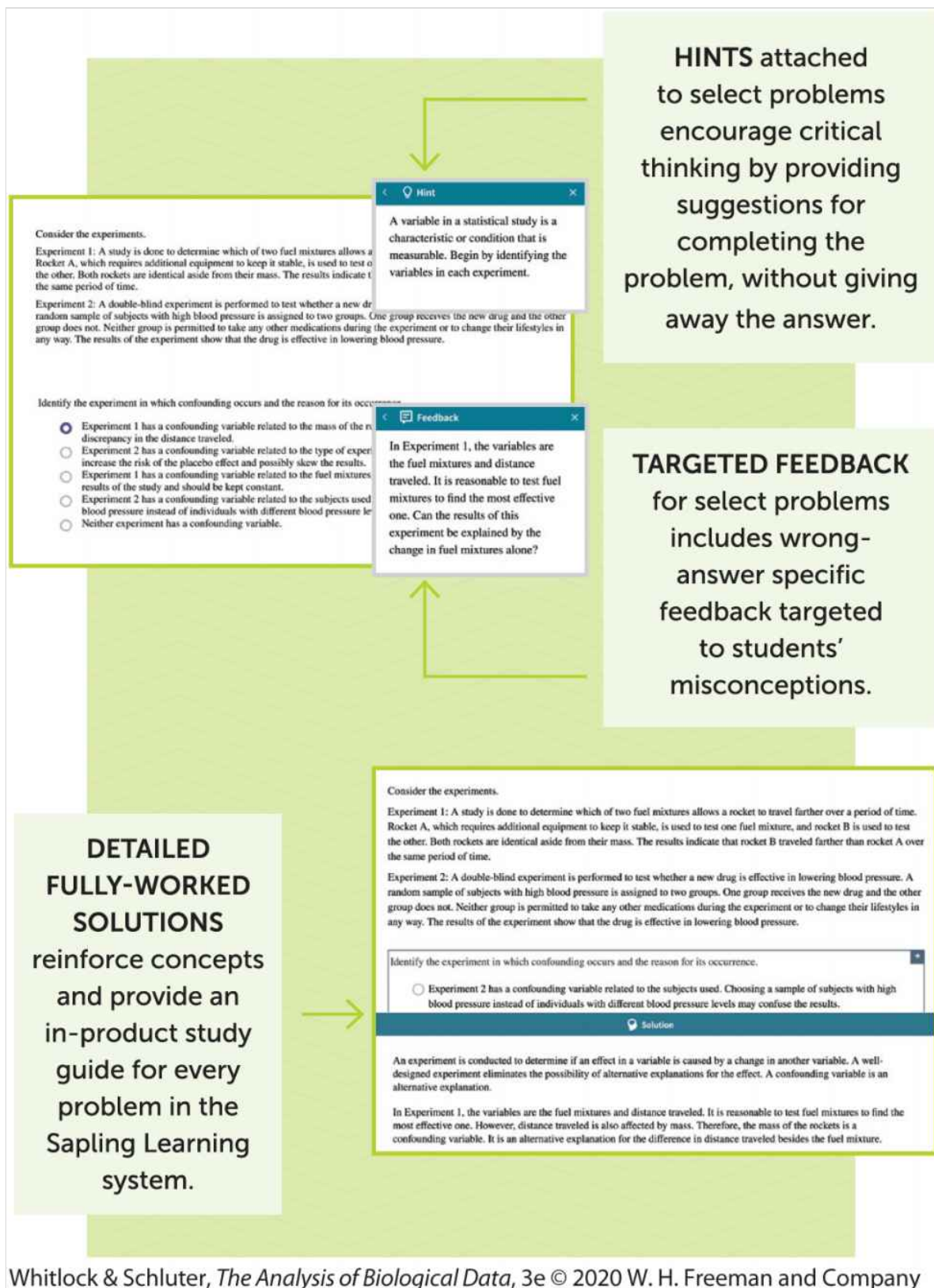
Finally, we would like to give great thanks to all of the people that have taught us the most over the years. MCW would like to thank Dave McCauley, Mike Wade, Nick Barton, Ben Pierce, Kevin Fowler, Patrick Phillips, Sally Otto, and Betty Whitlock. Nancy Heckman and Don Ludwig enlightened DS on many things about data and the theory and practice of statistics.

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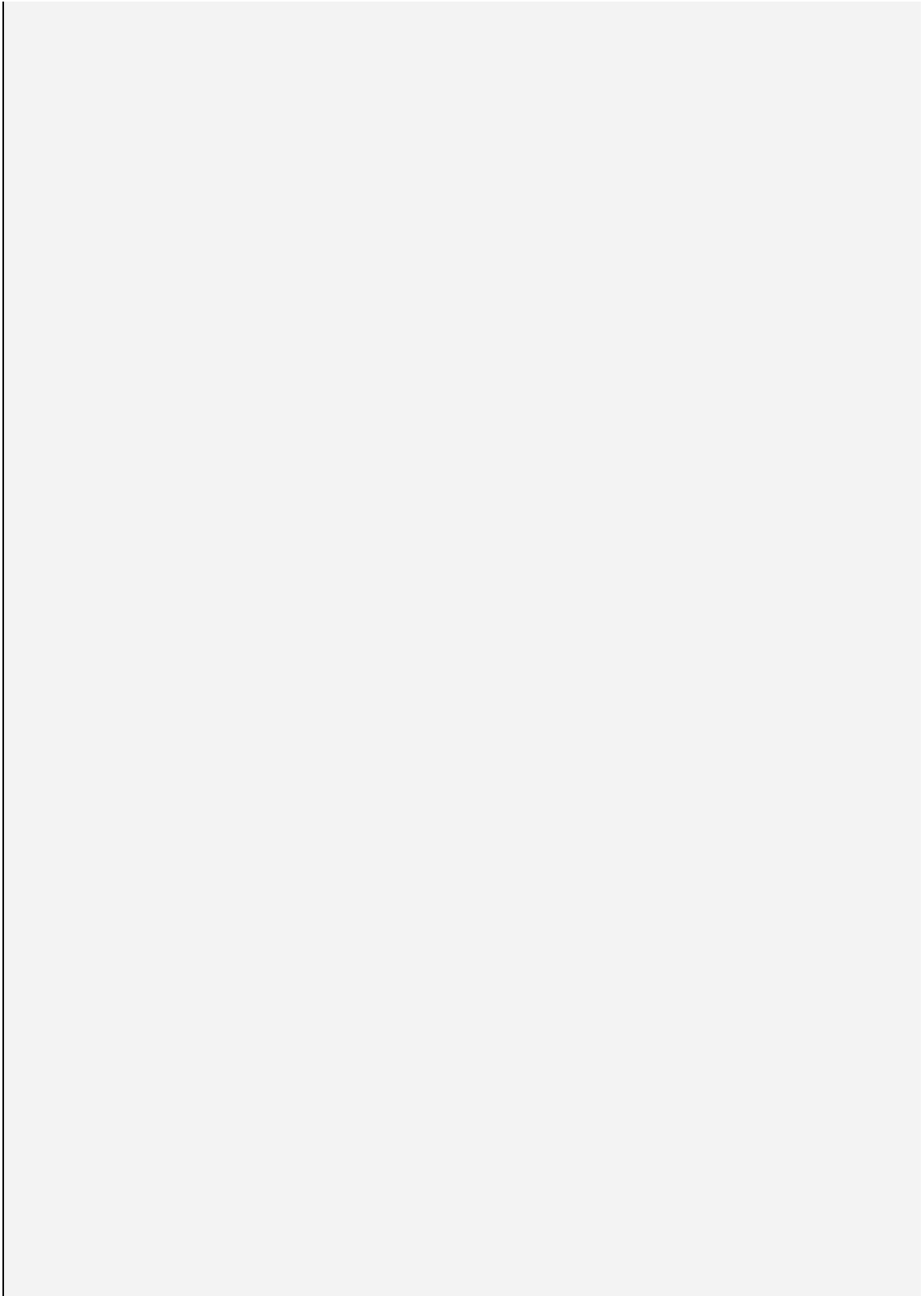
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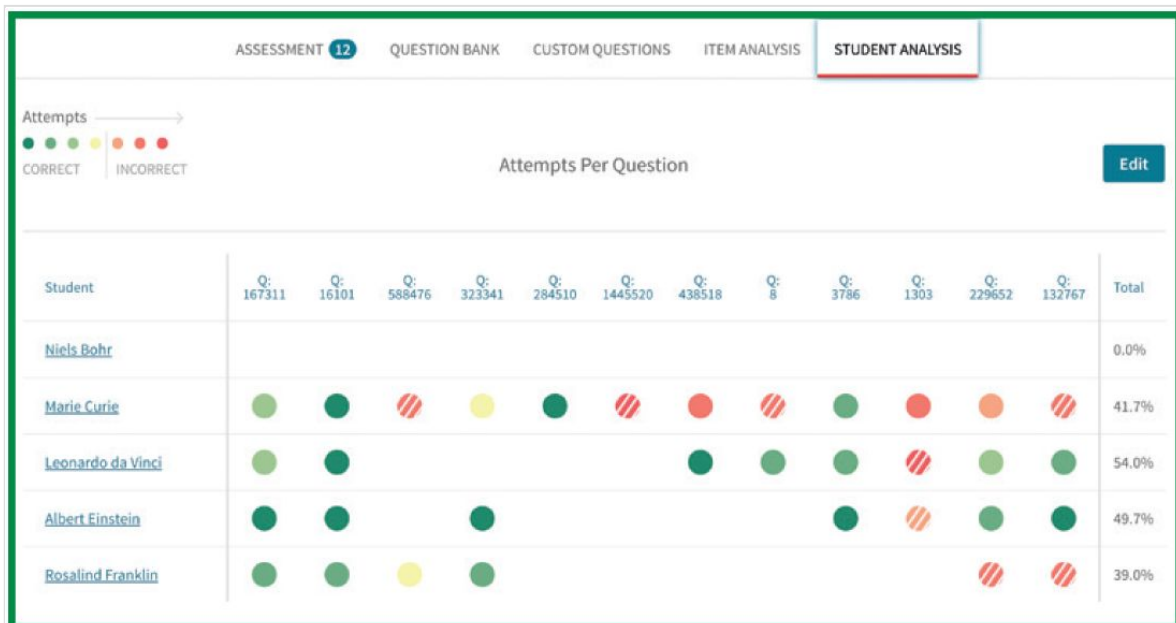


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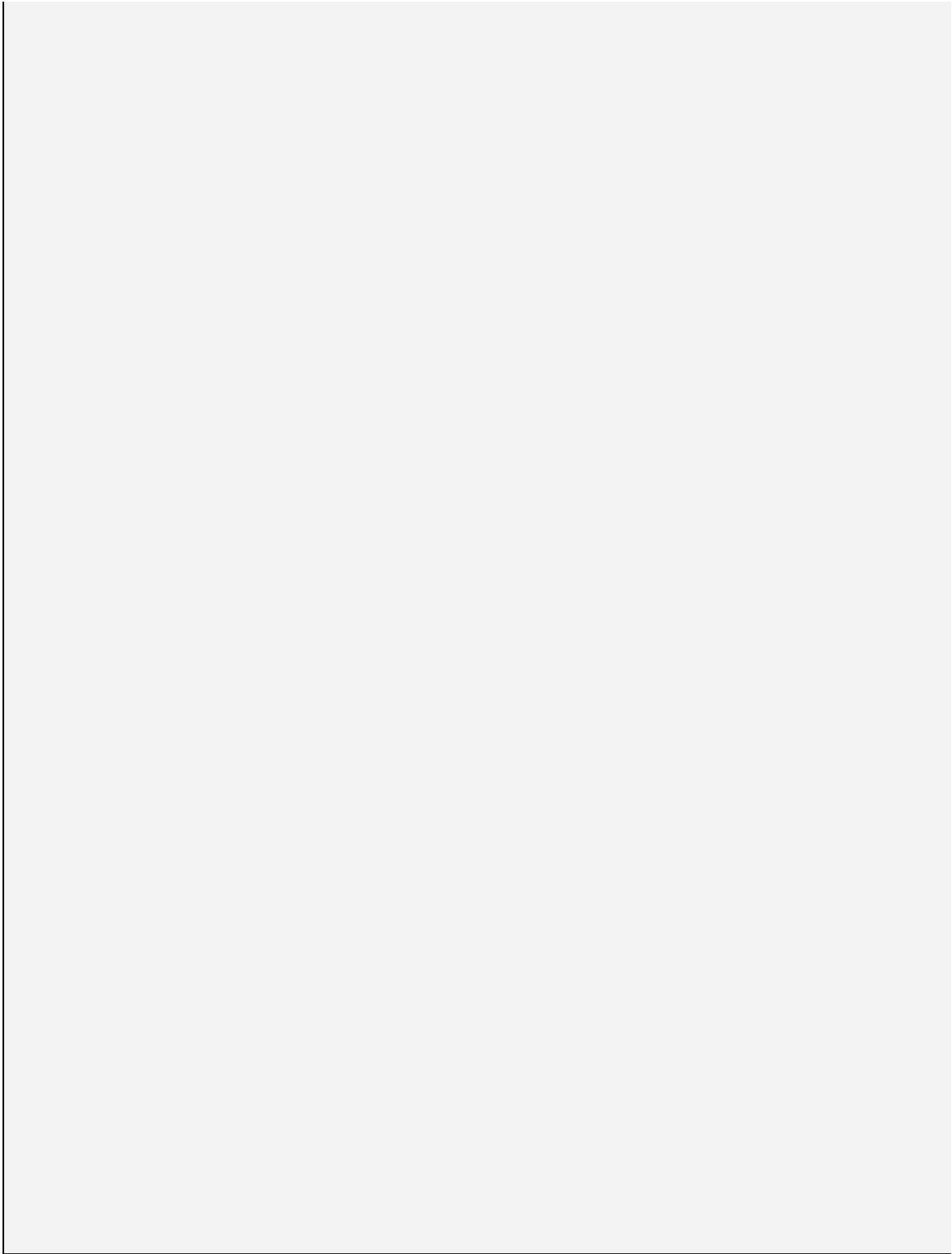
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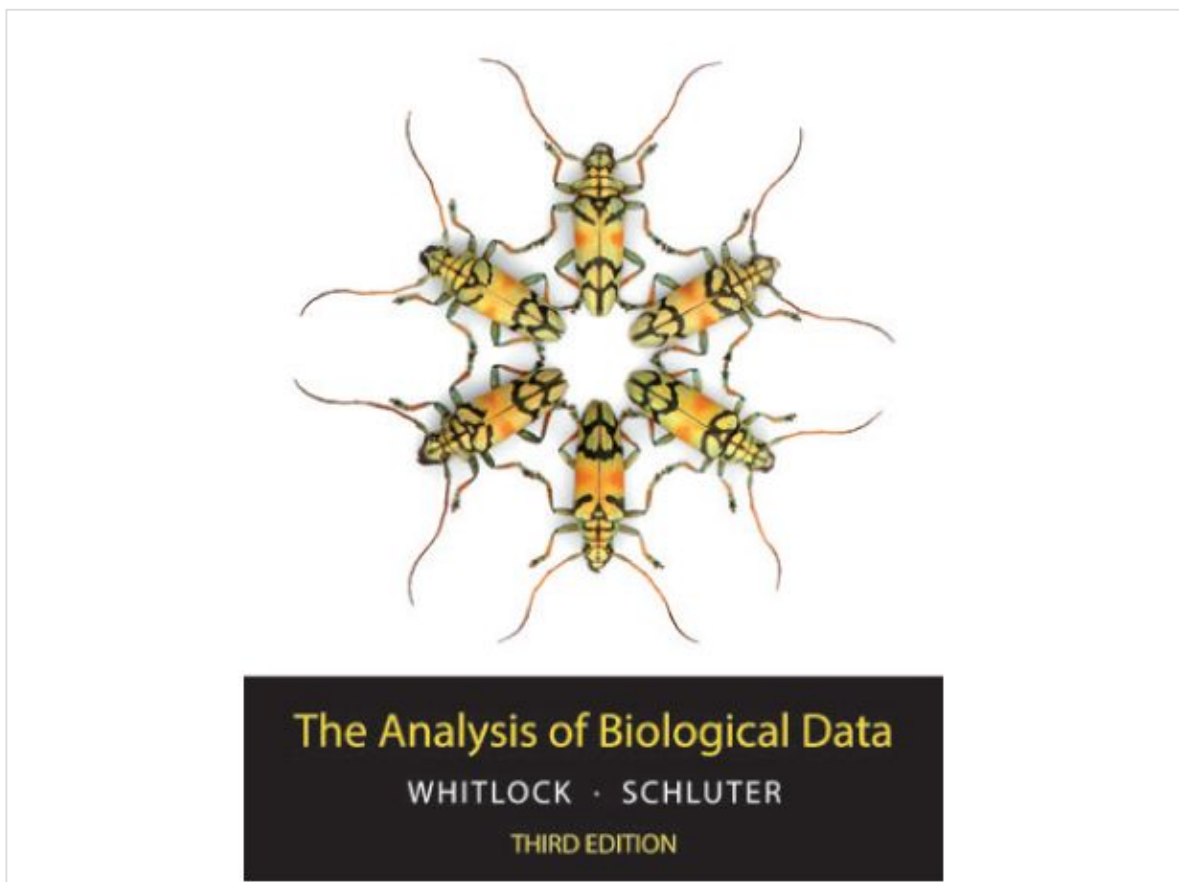
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For every chapter in the book, instructors are provided with a test bank of relevant questions, clicker questions that address all key concepts, and lecture PowerPoint presentations. All of these materials have been prepared by a team of statistical education specialists.

Online Resources for Students

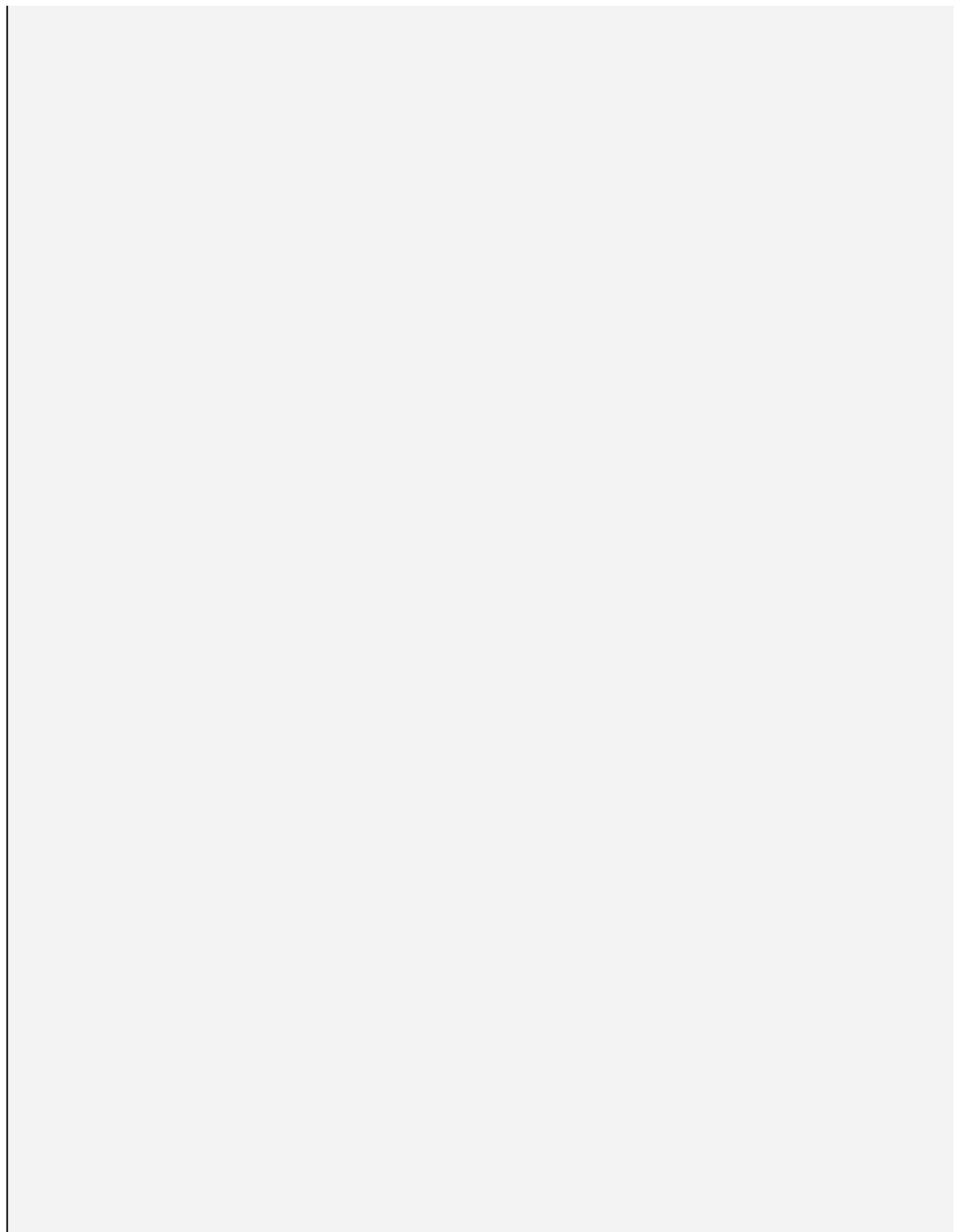
Many online resources are available to help students learn each of the key concepts and skills in the book. These are located on the authors' website at whitlockschluter3e.zoology.ubc.ca and via www.saplinglearning.com.

A link to a web page listing all resources available for each chapter is provided near the summary section of each chapter in the book.



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Interactive e-book

With the e-book, students can search, highlight, and bookmark specific information, making it easier to study and access key content. Media assets

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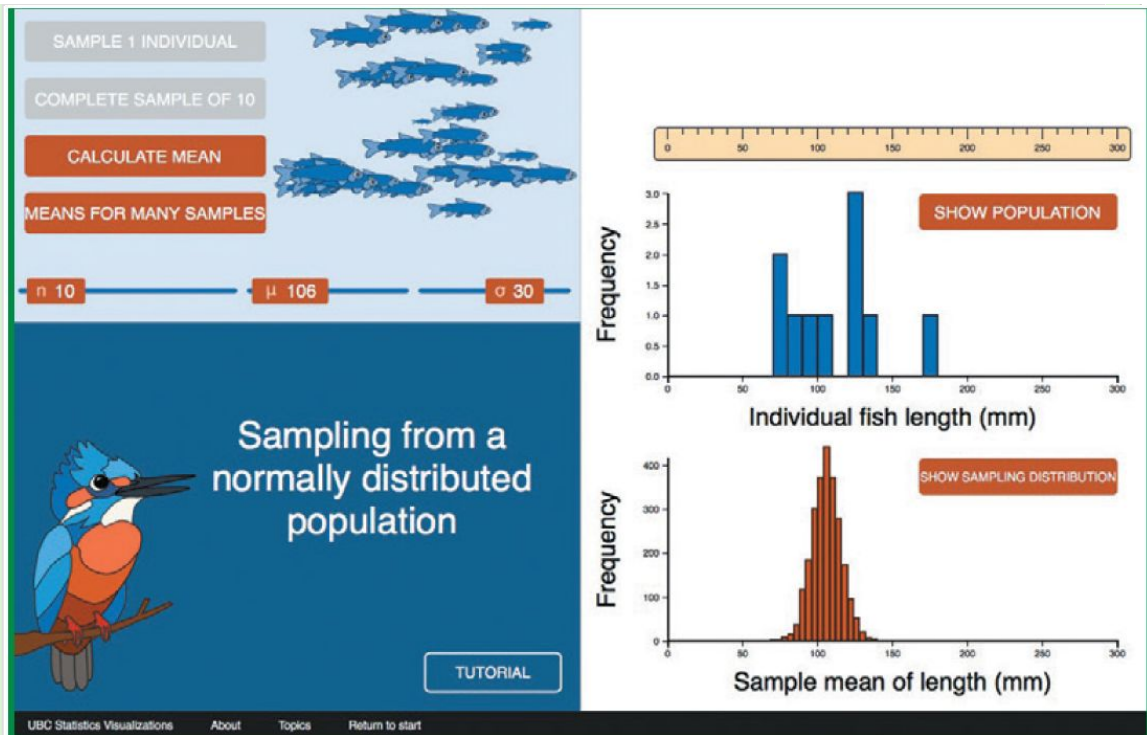
R code is provided to reproduce the complete analysis of all examples presented in the main text of the book. This resource enables students to learn R further by example. The code is available online at whitlockschluter3e.zoology.ubc.ca.

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