Genetics

A Conceptual Approach

sixth edition

Benjamin A. Pierce
Southwestern University

w.h. freeman
Macmillan Learning
New York

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To my parents, Rush and Amanda Pierce;

my children, Sarah Pierce Dumas and Michael Pierce;

and my genetic partner, friend, and soul mate

for 36 years, Marlene Tyrrell

Contents in Brief

Contents

Letter from the Author

I still remember the excitement I felt when I was in your place, taking my first genetics course. I was intrigued by the principles of heredity, which allow one to predict what offspring will look like even before they are born. I was fascinated to learn that these principles have their foundation in the chemistry of an elegant molecule called DNA. And I was captivated to find that genetics underlies evolution, the process responsible for life's endless diversity and beauty. These elements of genetics still impress and excite me today. One of the great things about teaching genetics is the chance to convey that excitement to students.

[Marlene Tyrrell]

This book has been written in many different places: in my office at Southwestern University, on the back porch of my home overlooking the hills

of central Texas, in airports and hotel rooms around the country. Regardless of location, whenever I write, I try to imagine that I'm sitting with a small group of students, having a conversation about genetics. My goal as the author of *Genetics: A Conceptual Approach* is to have that conversation with you. I want to become a trusted guide on your journey through introductory genetics. In this book, I've tried to share some of what I've learned in my years of teaching genetics. I provide advice and encouragement at places where students often have difficulty, and I tell stories of the people, places, and experiments of genetics—past and present—to keep the subject relevant, interesting, and alive. My goal is to help you learn the necessary details, concepts, and problem-solving skills while encouraging you to see the elegance and beauty of the larger landscape.

At Southwestern University, my office door is always open, and my students often drop by to share their own approaches to learning, things that they have read about genetics, and their experiences, concerns, and triumphs. I learn as much from my students as they learn from me, and I would love to learn from you—by email (pierceb@southwestern.edu), by telephone (512-863-1974), or in person (Southwestern University, Georgetown, Texas).

Ben Pierce

PROFESSOR OF BIOLOGY AND

HOLDER OF THE LILLIAN NELSON PRATT CHAIR

SOUTHWESTERN UNIVERSITY

Preface

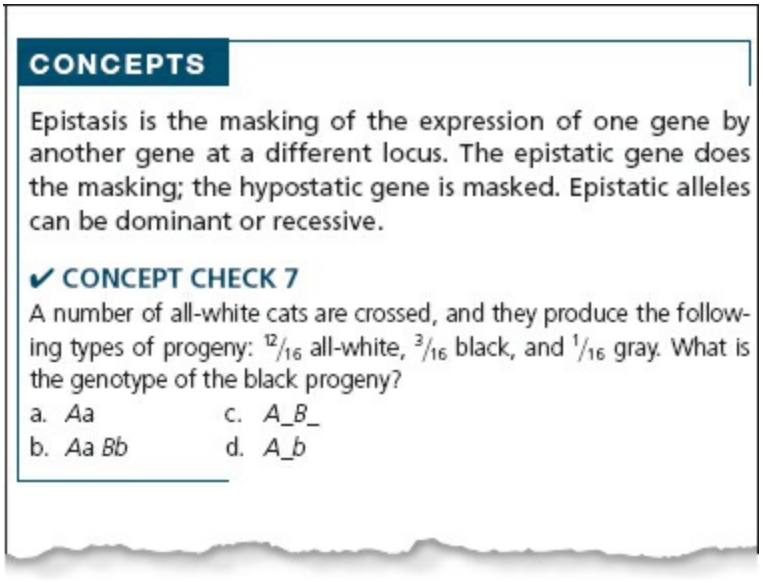
The main goals of *Genetics: A Conceptual Approach* have always been to help students uncover and make connections between the major concepts of genetics. Throughout the five preceding editions of this book, its accessible writing style, simple and instructive illustrations, and useful pedagogical features have helped students develop a fuller understanding of genetics.

Hallmark Features

Key Concepts and Connections Throughout the book, I've included features to help students focus on the major concepts of each topic.

Concepts boxes throughout each chapter summarize the key points of the preceding section. ***Concept Checks*** allow students to quickly assess their understanding of the material they've just read. Concept Checks are in multiple-choice or short-answer format, and their answers are given at the end of each chapter.

Connecting Concepts sections compare and contrast processes or integrate ideas across sections and chapters to help students see how different genetics topics relate to one another. All major concepts in each chapter are listed in the ***Concepts Summary*** at the end of the chapter.



CONCEPTS

Epistasis is the masking of the expression of one gene by another gene at a different locus. The epistatic gene does the masking; the hypostatic gene is masked. Epistatic alleles can be dominant or recessive.

✔ **CONCEPT CHECK 7**

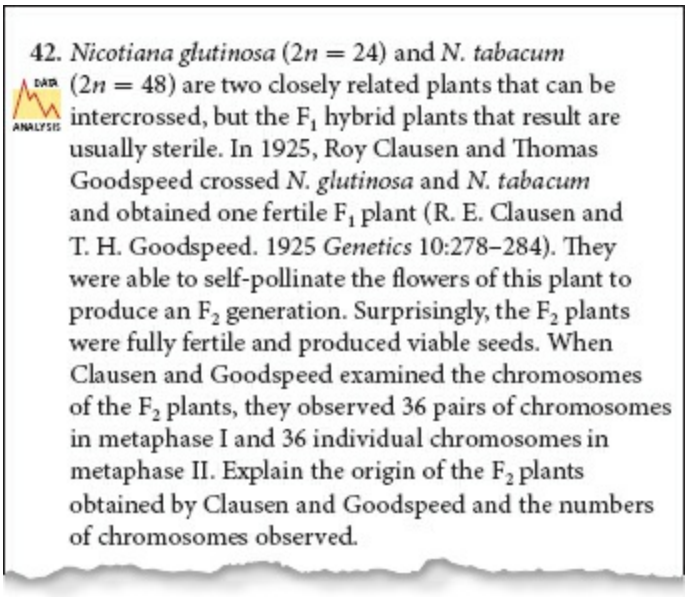
A number of all-white cats are crossed, and they produce the following types of progeny: $^{12}/_{16}$ all-white, $^{3}/_{16}$ black, and $^{1}/_{16}$ gray. What is the genotype of the black progeny?

a. *Aa*
b. *Aa Bb*
c. *A_B_*
d. *A_b*

Accessibility The conversational writing style of this book has always been a favorite

feature for both students and instructors. In addition to carefully walking students through each major concept of genetics, I invite them into the topic with an **introductory story**. These stories include relevant examples of diseases or other biological phenomena to give students a sample of what they'll be learning in a chapter. More than a third of the introductory stories in this edition are new.

Clear, Simple Illustration Program The attractive and instructive figures have proved to be an effective learning tool for students throughout the past five editions and continue to be a signature feature of the new edition. Each figure has been carefully rendered to highlight main points and to step the reader through experiments and processes. Most figures include text that walks students through the graphical presentation. Illustrations of experiments reinforce the scientific method by first proposing a hypothesis, then pointing out the methods and results, and ending with a conclusion that reinforces concepts explained in the text.


42. *Nicotiana glutinosa* ($2n = 24$) and *N. tabacum* ($2n = 48$) are two closely related plants that can be intercrossed, but the F_1 hybrid plants that result are usually sterile. In 1925, Roy Clausen and Thomas Goodspeed crossed *N. glutinosa* and *N. tabacum* and obtained one fertile F_1 plant (R. E. Clausen and T. H. Goodspeed. 1925 *Genetics* 10:278–284). They were able to self-pollinate the flowers of this plant to produce an F_2 generation. Surprisingly, the F_2 plants were fully fertile and produced viable seeds. When Clausen and Goodspeed examined the chromosomes of the F_2 plants, they observed 36 pairs of chromosomes in metaphase I and 36 individual chromosomes in metaphase II. Explain the origin of the F_2 plants obtained by Clausen and Goodspeed and the numbers of chromosomes observed.

Emphasis on Problem Solving One of the things that I've learned in my 36 years of teaching is that students learn genetics best through problem solving. Working through an example, equation, or experiment helps students see concepts in action and reinforces the ideas explained in the text. In the book, I help students develop problem-solving skills in a number of ways. **Worked Problems** walk students through each step of a difficult concept. **Problem Links** spread throughout each chapter point to end-of-chapter problems that students can work to test their understanding of the material they have just read, all with answers in the back of the book so that students can check their results. I provide a wide range of end-of-chapter problems, organized by chapter section and split into Comprehension Questions, Application Questions and Problems, and Challenge Questions. Some of these questions, marked by a data analysis icon, draw on examples from published, and cited, research articles.

New to the Sixth Edition

NEW SaplingPlus for Genetics: *A Conceptual Approach* The sixth edition is now fully supported in SaplingPlus. This comprehensive and robust online teaching and learning platform incorporates online homework with the e-Book, all instructor and student resources, and powerful gradebook functionality. Students benefit from just-in-time hints and feedback specific to their misconceptions to develop their problem-solving skills, while instructors benefit from automatically graded homework and robust gradebook diagnostics.

NEW Active learning components One of my main goals for this new edition is to provide better resources for active learning. In this edition, I have added Think-Pair-Share questions, which require students to work, and learn, in groups. These questions not only focus on the genetics topics covered in the chapter, but also tie them to genetics in medicine, agriculture, and other aspects of human society. An online instructor guide provides resources for instructors leading the in-class discussion.

Chapter Opening Think-Pair-Share Questions get students to discuss the chapter opening story itself and to connect it with what they know about genetics.

End-of-Chapter Think-Pair-Share Questions provide more challenging problem solving for students to work on in groups and encourage them to discuss the bigger-picture aspects of the material they learned in the chapter. They also allow students to connect the material they have learned to broader genetics topics.

THINK-PAIR-SHARE

- Most cells are unable to copy the ends of chromosomes, and therefore chromosomes shorten with each cell division. This limits the number of times a cell can divide. In germ cells and stem cells, however, an enzyme called telomerase lengthens the telomeres and prevents chromosome shortening. Thus, these cells are not limited in the number of times they can divide. All cells have the gene for telomerase, but most somatic cells don't express it, and they produce no telomerase. Why don't somatic cells express telomerase and have unlimited division?

- The introduction to this chapter discussed recent research showing that children who experience early childhood stresses have shorter telomeres. How might this information be used in a practical sense?

New and Reorganized Content

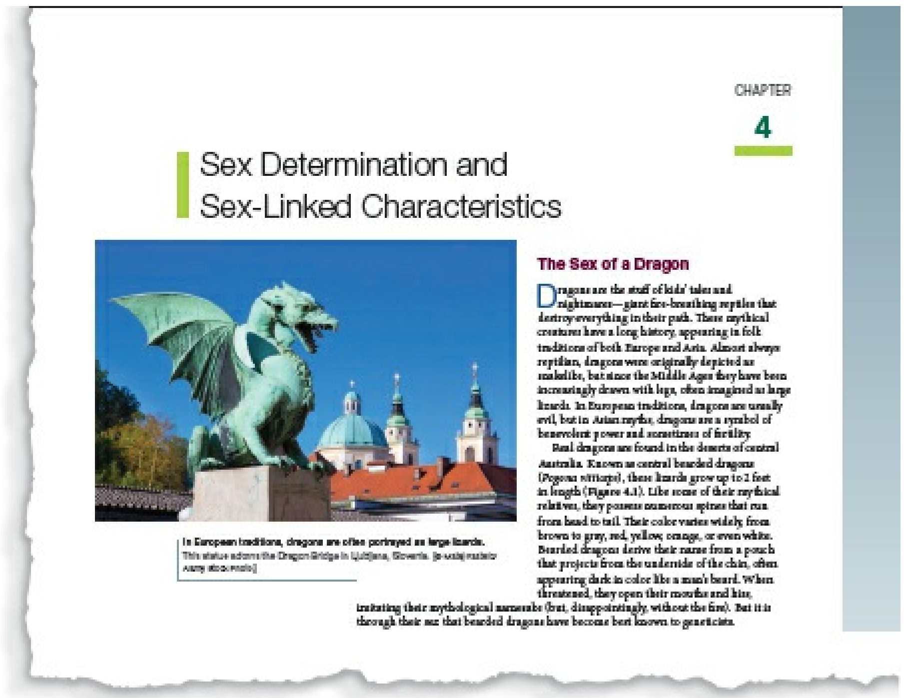
The sixth edition addresses recent discoveries in genetics corresponding to our ever-changing understanding of inheritance, the molecular nature of genetic information, epigenetics, and genetic evolution. This edition also focuses on updating the new research techniques that have become available to geneticists in the past few years. For example, I have expanded coverage of CRISPR-Cas systems and reorgrnized the chapter on molecular genetic analysis.

New and updated content includes

New section on DNA in the biosphere (Chapter 1)
New sections on genetic mosaicism and pharmacogenetic testing (Chapter 6)
Expanded discussion of aneuploidy in humans (Chapter 8)
New section on the importance of bacterial and viral genetics; new section on bacterial defense mechanisms; new section on rhinoviruses (Chapter 9)
Updated discussion of chromatin structure; new section on mitochondrial replacement therapy (Chapter 11)
Updated discussion of licensing of DNA replication; updated discussion of the endreplication problem for telomeres (Chapter 12)
Expanded discussion of Piwi-interacting RNAs; revised section on CRISPR RNA; expanded discussion of long noncoding RNAs (Chapter 14)
Expanded discussion of enhancers and insulators; expanded discussion of gene regulation through RNA splicing; new section on RNA crosstalk; expanded discussion of translational control of gene expression (Chapter 17)
Significant reorganization to focus on methods currently in use; significant updates on new technologies; new section on CRISPR-Cas genome editing; expanded section on engineered nucleases (Chapter 19)
Updated methods in genomics; new sections “What Exactly Is the Human Genome?” and “RNA Sequencing” (Chapter 20)
Updates for cancer statistics; expanded discussion of telomerase in human cancers; expanded discussion of genetics of tumor metastases (Chapter 23)
A new section on population variation; an expanded discussion on the reproductive isolation of apple maggot flies (Chapter 26)

NEW Introductory Stories Each chapter begins with a brief **introductory story** that illustrates the relevance of a genetic concept that students will learn

in the chapter. These stories—a favorite feature of past editions—give students a glimpse of what's going on in the field of genetics today and help to draw the reader into the chapter. Among new introductory story topics are "The Sex of a Dragon," "The Genetics of Medieval Leprosy," "Editing the Genome with CRISPR-Cas9," "Building a Chromosome for Class," and "The Wolves of Isle Royale." End-of-chapter problems specifically address concepts discussed in many of the introductory stories, both old and new.


CHAPTER 4

Sex Determination and Sex-Linked Characteristics

In European traditions, dragons are often portrayed as large lizards. This statue adorns the Dragon Bridge in Ljubljana, Slovenia.

The Sex of a Dragon

Dragons are the stuff of kids' tales and nightmares—giant fire-breathing reptiles that destroy everything in their path. These mythical creatures have a long history, appearing in folk traditions of both Europe and Asia. Almost always reptilian, dragons were originally depicted as snakelike, but since the Middle Ages they have been increasingly drawn with legs, often imagined as large lizards. In European traditions, dragons are usually evil, but in Asian myths, dragons are a symbol of benevolent power and sometimes of fertility.

Real dragons are found in the deserts of central Australia. Known as central bearded dragons (*Pogona vitticeps*), these lizards grow up to 2 feet in length (Figure 4.1). Like some of their mythical relatives, they possess numerous spines that run from head to tail. Their color varies widely, from brown to gray, red, yellow, orange, or even white. Bearded dragons derive their name from a pouch that projects from the underside of the chin, often appearing dark in color like a man's beard. When threatened, they open their mouths and hiss, imitating their mythological namesake (but, disappointingly, without the fire). But it is through their sex that bearded dragons have become best known to geneticists.

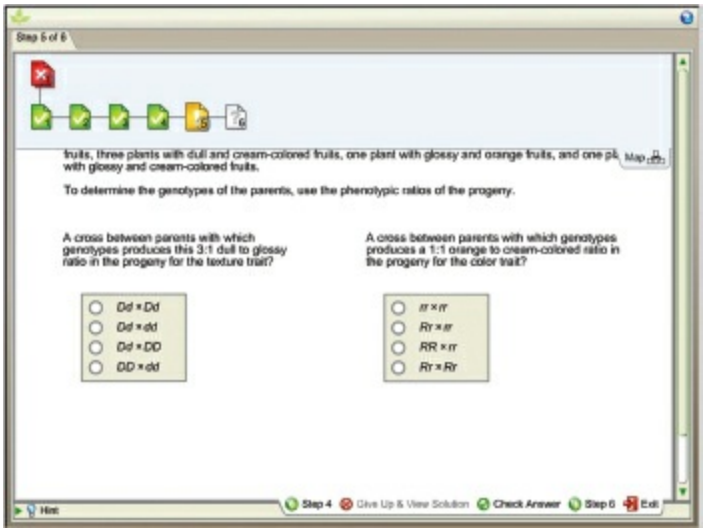
Media and Supplements

For this edition, we have thoroughly revised and refreshed the extensive set of online learning tools for Genetics: *A Conceptual Approach*. All of the new media resources for this edition will be available in our new SaplingPlus system.

SaplingPlus is a comprehensive and robust online teaching and learning platform that also incorporates all instructor resources and gradebook functionality.

Student Resources in SaplingPlus for *Genetics: A Conceptual Approach*

SaplingPlus provides students with media resources designed to enhance their understanding of genetic principles and improve their problem-solving ability.



Detailed Feedback for Students Homework questions include hints, wrong-answer feedback targeted to students' misconceptions, and fully worked out solutions to reinforce concepts and to build problem-solving skills.

The e-Book The e-Book contains the full contents of the text as well as embedded links to important media resources (listed following).

Updated and New Problem-Solving Videos offer students valuable help by reviewing basic problem-solving strategies. The problemsolving videos demonstrate an instructor working through problems that students find difficult in a step-by-step manner.

New Online Tutorials identify where students have difficulty with a problem and route them through a series of steps in order to reach the correct answer. Hints and feedback at every step guide students along the way, as if they were working the problem with an instructor. Complete solutions are also included.

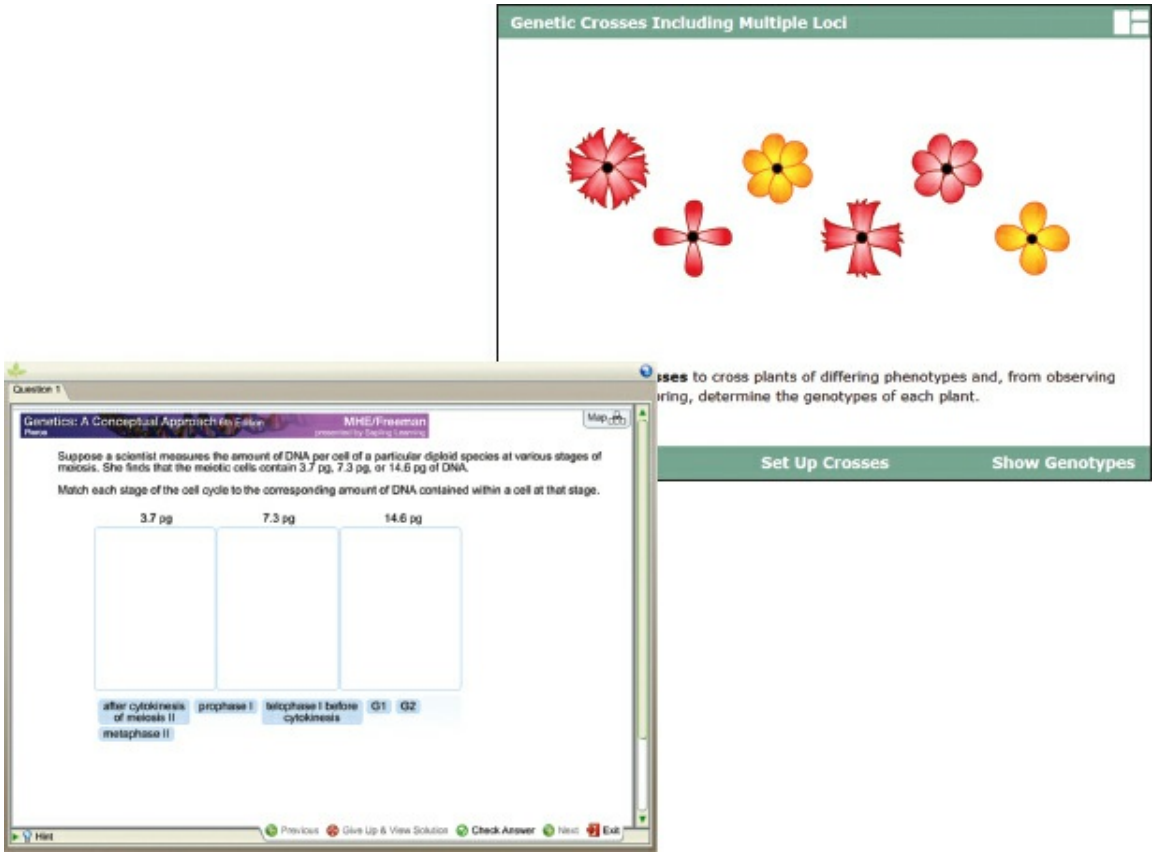
Updated and New Animations/Simulations help students understand key processes in genetics by outlining them in a step-by-step manner. All of the animations and simulations include assessment questions to help students evaluate whether they understood the concept or technique they viewed.

Comprehensively Revised Assessment All media resources have undergone extensive rewriting, reviewing, and accuracy checking.

Online Reading Quizzes, covering the key concepts in each chapter, allow instructors to assess student preparedness before class and to identify challenging areas.

New Online Homework. SaplingPlus offers robust, high-level homework questions with hints and wrong-answer feedback targeted to students' misconceptions as well as detailed

worked-out solutions to reinforce concepts. Online Homework includes select end-of-chapter Application Problems from the text, converted into a variety of auto-graded formats. It also includes a variety of Sapling Genetics questions, curated for alignment with the text. These questions can also be used for quizzing or student practice. The questions are tagged by difficulty level.



The printable **Test Bank** contains at least 50 multiple-choice and short-answer questions per chapter. The Test Bank questions are also available in a downloadabl Diploma format.

New In-Class Activities contribute to active learning of some of the more challenging topics in genetics. Ten activities (15–45 minutes in length) allow students to work in groups to apply what they have learned to problems ranging from gene mapping to statistical analysis to interpreting phylogenetic trees. Each activity includes clicker questions and multiple-choice assessment questions.

Nature Genetics Articles with Assessment engage students with primary research and encourage critical thinking. Specifically selected for both alignment with text coverage and exploration of identified difficult topics, the *Nature Genetics* articles include assessment questions that can be automatically graded. Some of the openended (non-multiple-choice) questions are also suitable for use in flipped classrooms and active learning discussions either in class or online.

Instructor Resources in SaplingPlus for *Genetics: A Conceptual Approach*

Updated Clicker Questions allow instructors to integrate active learning into the classroom and to assess students' understanding of key concepts during lectures. Available in PowerPoint format, numerous questions are based on the Concept Check questions featured in the textbook.

Updated Lecture PowerPoint Files have been developed to minimize preparation time for new users of the book. These files offer suggested lectures, including key illustrations and summaries, that instructors can adapt to their teaching styles.

Layered PowerPoint Slides deconstruct key concepts, sequences, and processes from the textbook illustrations, allowing instructors to present complex ideas step by step.

Textbook Illustrations and Tables are offered as high-resolution JPEG files. Each image has been fully optimized to increase type sizes and adjust color saturation. These images have been tested in a large lecture hall to ensure maximum clarity and visibility. Images are presented in both labeled and unlabeled formats.

The **Solutions and Problem-Solving Manual** (written by Jung Choi and Mark McCallum) contains complete answers and worked-out solutions to all questions and problems in the textbook. The Solutions Manual is also available in print (ISBN: 1-319-08870-8).

Acknowledgments

I am indebted to many people for help with this and previous editions of *Genetics*: A *Conceptual Approach*. I learned much from my genetics teachers: Ray Canham, who first exposed me to genetics and instilled in me a life-long love for the subject; and Jeff Mitton, who taught me the art of genetic research. I've learned from the thousands of genetics students who have filled my classes over the past 36 years, first at Connecticut College, then at Baylor University, and now at Southwestern University. Their intelligence, enthusiasm, curiosity, and humor have been a source of motivation and pleasure throughout my professional life. I have also learned from students worldwide who have used earlier editions of this book and kindly shared with me— through emails and phone calls—their thoughts about the book and how it could be improved.

I am grateful for the wonderful colleagues who surround me daily at Southwestern University and whose friendship, advice, and good humor sustain my work. The small classes, close interaction of students and faculty, and integration of teaching and research have made working at Southwestern

University personally and professionally rewarding. I thank Edward Burger, President of Southwestern University and Alisa Gaunder, Dean of the Faculty, for sustaining this supportive academic environment and for their continued friendship and collegiality.

Writing a modern science textbook requires a team effort, and I have been blessed with an outstanding team at W. H. Freeman and Macmillan Learning. Managing Director Susan Winslow has been a champion of the book for a number of years; I value her support, strategic vision, and commitment to education. Lauren Schultz, Executive Editor, has been a great project leader. She has been a continual source of encouragement, support, and creative ideas, as well as a good friend and colleague. Working daily with Development Editor Maria Lokshin has been a wonderful experience. Maria's hard work, passion for excellence, superior knowledge of genetics, great organizational skills, and good humor made crafting this edition rewarding and fun, in spite of a demanding schedule. I am also grateful to Lisa Samols, Director of Development, for shepherding the development of this edition and for great insight at key points.

Norma Sims Roche was an outstanding manuscript editor, making numerous suggestions that kept the text accurate and consistent and that also greatly improved its readability. Project Editor Jennifer Carey expertly managed the production of this sixth edition. Her dedication to excellence in all phases of the production process has been a major factor in making the book a success. I thank Dragonfly Media Group for creating and revising the book's illustrations and Janice Donnola for coordinating the illustration program. Quade Paul (Echo Medical Media) designed the cover image (from a concept by Emiko Paul). Thanks to Paul Rohloff at W. H. Freeman and Sofia Buono at codeMantra for coordinating the composition and manufacturing phases of production. Blake Logan developed the book's design. I thank Christine Buese and Richard Fox for photo research. Amy Thorne, Cassandra Korsvik, Amber Jonker, Clairissa Simmons, Amanda Nietzel, Elaine Palucki, and Emiko Paul developed the excellent media and supplements that accompany the book. I am grateful to Jung Choi and Mark McCallum for writing solutions to new end-of-chapter problems. Robert Fowler, Marcie Moehnke, Ellen France, Amy McMillan, Daniel Williams, Douglas Thrower, Victor Fet, and Usha Vivegananthan developed and reviewed assessment questions.

As always, I am grateful to the Macmillan Learning sales representatives,

regional managers, and STEM specialists, who introduce my book to genetic instructors throughout the world. I have greatly enjoyed working with this sales staff; their expertise, hard work, and good service are responsible for the success of Macmillan books.

A number of colleagues served as reviewers of this book, kindly lending me their technical expertise and teaching experience. Their assistance is gratefully acknowledged. Any remaining errors are entirely my own.

Marlene Tyrrell—my spouse and best friend for 36 years—our children and their spouses—Sarah, Matt, Michael, and Amber—and now my F_2 progeny—Ellie, Beckett, and Caroline—provide love, support, and inspiration for everything I do.

My gratitude goes to the reviewers of this new edition of *Genetics: A Conceptual Approach*:

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