

Contents

1 Introduction to Genetics 1

- 1.1 Genetics Has an Interesting Early History 2
 - 1.2 Genetics Progressed from Mendel to DNA in Less Than a Century 3
 - 1.3 Discovery of the Double Helix Launched the Era of Molecular Genetics 4
 - 1.4 Development of Recombinant DNA Technology Began the Era of DNA Cloning 6
 - 1.5 The Impact of Biotechnology Is Continually Expanding 7
 - 1.6 Genomics, Proteomics, and Bioinformatics Are New and Expanding Fields 8
 - 1.7 Genetic Studies Rely on the Use of Model Organisms 8
 - 1.8 Genetics Has Had a Profound Impact on Society 10
- Problems and Discussion Questions 11

2 Mitosis and Meiosis 12

- 2.1 Cell Structure Is Closely Tied to Genetic Function 13
- 2.2 Chromosomes Exist in Homologous Pairs in Diploid Organisms 15
- 2.3 Mitosis Partitions Chromosomes into Dividing Cells 17
- 2.4 Meiosis Creates Haploid Gametes and Spores and Enhances Genetic Variation in Species 21
- 2.5 The Development of Gametes Varies in Spermatogenesis Compared to Oogenesis 24
- 2.6 Meiosis Is Critical to Sexual Reproduction in All Diploid Organisms 26
- 2.7 Electron Microscopy Has Revealed the Physical Structure of Mitotic and Meiotic Chromosomes 26

■ EXPLORING GENOMICS

PubMed: Exploring and Retrieving Biomedical Literature 27

CASE STUDY: Timing is everything 28

Insights and Solutions 28

Problems and Discussion Questions 29

3 Mendelian Genetics 31

- 3.1 Mendel Used a Model Experimental Approach to Study Patterns of Inheritance 32
- 3.2 The Monohybrid Cross Reveals How One Trait Is Transmitted from Generation to Generation 33
- 3.3 Mendel's Dihybrid Cross Generated a Unique F_2 Ratio 36
- 3.4 The Trihybrid Cross Demonstrates That Mendel's Principles Apply to Inheritance of Multiple Traits 39
- 3.5 Mendel's Work Was Rediscovered in the Early Twentieth Century 41

■ EVOLVING CONCEPT OF THE GENE 42

- 3.6 Independent Assortment Leads to Extensive Genetic Variation 42
- 3.7 Laws of Probability Help to Explain Genetic Events 42
- 3.8 Chi-Square Analysis Evaluates the Influence of Chance on Genetic Data 43
- 3.9 Pedigrees Reveal Patterns of Inheritance of Human Traits 46
- 3.10 Tay-Sachs Disease: The Molecular Basis of a Recessive Disorder in Humans 48

■ EXPLORING GENOMICS

Online Mendelian Inheritance in Man 49

CASE STUDY: To test or not to test 50

Insights and Solutions 50

Problems and Discussion Questions 51

4 Modification of Mendelian Ratios 53

- 4.1 Alleles Alter Phenotypes in Different Ways 54
- 4.2 Geneticists Use a Variety of Symbols for Alleles 54
- 4.3 Neither Allele Is Dominant in Incomplete, or Partial, Dominance 55
- 4.4 In Codominance, the Influence of Both Alleles in a Heterozygote Is Clearly Evident 56
- 4.5 Multiple Alleles of a Gene May Exist in a Population 56
- 4.6 Lethal Alleles Represent Essential Genes 58

■ EVOLVING CONCEPT OF THE GENE 58

- 4.7 Combinations of Two Gene Pairs with Two Modes of Inheritance Modify the 9:3:3:1 Ratio 59
- 4.8 Phenotypes Are Often Affected by More Than One Gene 60
- 4.9 Complementation Analysis Can Determine if Two Mutations Causing a Similar Phenotype Are Alleles of the Same Gene 64
- 4.10 Expression of a Single Gene May Have Multiple Effects 66
- 4.11 X-Linkage Describes Genes on the X Chromosome 66
- 4.12 In Sex-Limited and Sex-Influenced Inheritance, an Individual's Gender Influences the Phenotype 68
- 4.13 Genetic Background and the Environment Affect Phenotypic Expression 70
- 4.14 Extranuclear Inheritance Modifies Mendelian Patterns 72

■ GENETICS, ETHICS, AND SOCIETY

Mitochondrial Replacement and Three-Parent Babies 76

CASE STUDY: Is it all in the genes? 77

Insights and Solutions 77

Problems and Discussion Questions 78

5 Sex Determination and Sex Chromosomes 83

- 5.1 X and Y Chromosomes Were First Linked to Sex Determination Early in the Twentieth Century 84
- 5.2 The Y Chromosome Determines Maleness in Humans 85
- 5.3 The Ratio of Males to Females in Humans Is Not 1.0 88
- 5.4 Dosage Compensation Prevents Excessive Expression of X-Linked Genes in Humans and Other Mammals 89
- 5.5 The Ratio of X Chromosomes to Sets of Autosomes Can Determine Sex 92
- 5.6 Temperature Variation Controls Sex Determination in Reptiles 94

GENETICS, ETHICS, AND SOCIETY

A Question of Gender: Sex Selection in Humans 95

CASE STUDY: Is the baby a boy or a girl? 96

Insights and Solutions 97

Problems and Discussion Questions 97

6 Chromosome Mutations: Variation in Number and Arrangement 99

- 6.1 Variation in Chromosome Number: Terminology and Origin 100
- 6.2 Monosomy and Trisomy Result in a Variety of Phenotypic Effects 101
- 6.3 Polyploidy, in Which More Than Two Haploid Sets of Chromosomes Are Present, Is Prevalent in Plants 104
- 6.4 Variation Occurs in the Composition and Arrangement of Chromosomes 107
- 6.5 A Deletion Is a Missing Region of a Chromosome 108
- 6.6 A Duplication Is a Repeated Segment of a Chromosome 110
- 6.7 Inversions Rearrange the Linear Gene Sequence 112
- 6.8 Translocations Alter the Location of Chromosomal Segments in the Genome 113
- 6.9 Fragile Sites in Human Chromosomes Are Susceptible to Breakage 115

GENETICS, ETHICS, AND SOCIETY

Down Syndrome and Prenatal Testing—The New Eugenics? 117

CASE STUDY: Fish tales 118

Insights and Solutions 118

Problems and Discussion Questions 119

7 Linkage and Chromosome Mapping in Eukaryotes 121

- 7.1 Genes Linked on the Same Chromosome Segregate Together 122

- 7.2 Crossing Over Serves as the Basis of Determining the Distance between Genes during Mapping 123
- 7.3 Determining the Gene Sequence during Mapping Requires the Analysis of Multiple Crossovers 128
- 7.4 As the Distance between Two Genes Increases, Mapping Estimates Become More Inaccurate 135

EVOLVING CONCEPT OF THE GENE 136

- 7.5 Chromosome Mapping Is Now Possible Using DNA Markers and Annotated Computer Databases 137
- 7.6 Other Aspects of Genetic Exchange 137

EXPLORING GENOMICS

Human Chromosome Maps on the Internet 139

CASE STUDY: Links to autism 140

Insights and Solutions 140

Problems and Discussion Questions 141

8 Genetic Analysis and Mapping in Bacteria and Bacteriophages 144

- 8.1 Bacteria Mutate Spontaneously and Are Easily Cultured 145
- 8.2 Genetic Recombination Occurs in Bacteria 145
- 8.3 The F Factor Is an Example of a Plasmid 152
- 8.4 Transformation Is Another Process Leading to Genetic Recombination in Bacteria 153
- 8.5 Bacteriophages Are Bacterial Viruses 154
- 8.6 Transduction Is Virus-Mediated Bacterial DNA Transfer 157

GENETICS, ETHICS, AND SOCIETY

Multidrug-Resistant Bacteria: Fighting with Phage 158

CASE STUDY: To test or not to test 159

Insights and Solutions 159

Problems and Discussion Questions 160

9 DNA Structure and Analysis 161

- 9.1 The Genetic Material Must Exhibit Four Characteristics 162
- 9.2 Until 1944, Observations Favored Protein as the Genetic Material 162
- 9.3 Evidence Favoring DNA as the Genetic Material Was First Obtained during the Study of Bacteria and Bacteriophages 163
- 9.4 Indirect and Direct Evidence Supports the Concept That DNA Is the Genetic Material in Eukaryotes 168
- 9.5 RNA Serves as the Genetic Material in Some Viruses 169
- 9.6 The Structure of DNA Holds the Key to Understanding Its Function 169

EVOLVING CONCEPT OF THE GENE 175

- 9.7 Alternative Forms of DNA Exist 175

- 9.8 The Structure of RNA Is Chemically Similar to DNA, but Single Stranded 176
- 9.9 Many Analytical Techniques Have Been Useful during the Investigation of DNA and RNA 177

EXPLORING GENOMICS

Introduction to Bioinformatics: BLAST 178

CASE STUDY: Credit where credit is due 179

Insights and Solutions 180

Problems and Discussion Questions 180

10 DNA Replication 182

- 10.1 DNA Is Reproduced by Semiconservative Replication 183
- 10.2 DNA Synthesis in Bacteria Involves Five Polymerases, as Well as Other Enzymes 187
- 10.3 Many Complex Issues Must Be Resolved during DNA Replication 190
- 10.4 A Coherent Model Summarizes DNA Replication 193
- 10.5 Replication Is Controlled by a Variety of Genes 194
- 10.6 Eukaryotic DNA Replication Is Similar to Replication in Bacteria, but Is More Complex 195
- 10.7 Telomeres Solve Stability and Replication Problems at Eukaryotic Chromosome Ends 196

GENETICS, ETHICS, AND SOCIETY

Telomeres: The Key to a Long Life? 199

CASE STUDY: At loose ends 200

Insights and Solutions 200

Problems and Discussion Questions 201

11 Chromosome Structure and DNA Sequence Organization 202

- 11.1 Viral and Bacterial Chromosomes Are Relatively Simple DNA Molecules 203
- 11.2 Mitochondria and Chloroplasts Contain DNA Similar to Bacteria and Viruses 204
- 11.3 Specialized Chromosomes Reveal Variations in the Organization of DNA 206
- 11.4 DNA Is Organized into Chromatin in Eukaryotes 208
- 11.5 Eukaryotic Genomes Demonstrate Complex Sequence Organization Characterized by Repetitive DNA 212
- 11.6 The Vast Majority of a Eukaryotic Genome Does Not Encode Functional Genes 215

EXPLORING GENOMICS

Database of Genomic Variants: Structural Variations in the Human Genome 215

CASE STUDY: Helping or hurting? 216

Insights and Solutions 216

Problems and Discussion Questions 217

12 The Genetic Code and Transcription 218

- 12.1 The Genetic Code Exhibits a Number of Characteristics 219
- 12.2 Early Studies Established the Basic Operational Patterns of the Code 219
- 12.3 Studies by Nirenberg, Matthaei, and Others Deciphered the Code 220
- 12.4 The Coding Dictionary Reveals the Function of the 64 Triplets 225
- 12.5 The Genetic Code Has Been Confirmed in Studies of Bacteriophage MS2 226
- 12.6 The Genetic Code Is Nearly Universal 227
- 12.7 Different Initiation Points Create Overlapping Genes 227
- 12.8 Transcription Synthesizes RNA on a DNA Template 228
- 12.9 RNA Polymerase Directs RNA Synthesis 228
- 12.10 Transcription in Eukaryotes Differs from Bacterial Transcription in Several Ways 231
- 12.11 The Coding Regions of Eukaryotic Genes Are Interrupted by Intervening Sequences Called Introns 233

EVOLVING CONCEPT OF THE GENE 236

- 12.12 RNA Editing May Modify the Final Transcript 237
- 12.13 Transcription Has Been Visualized by Electron Microscopy 237

CASE STUDY: Treatment dilemmas 237

GENETICS, ETHICS, AND SOCIETY

Treating Duchenne Muscular Dystrophy with Exon-Skipping Drugs 238

Insights and Solutions 238

Problems and Discussion Questions 239

13 Translation and Proteins 241

- 13.1 Translation of mRNA Depends on Ribosomes and Transfer RNAs 241
- 13.2 Translation of mRNA Can Be Divided into Three Steps 245
- 13.3 High-Resolution Studies Have Revealed Many Details about the Functional Bacterial Ribosome 249
- 13.4 Translation Is More Complex in Eukaryotes 250
- 13.5 The Initial Insight That Proteins Are Important in Heredity Was Provided by the Study of Inborn Errors of Metabolism 251
- 13.6 Studies of *Neurospora* Led to the One-Gene: One-Enzyme Hypothesis 251
- 13.7 Studies of Human Hemoglobin Established That One Gene Encodes One Polypeptide 253

EVOLVING CONCEPT OF THE GENE 254

- 13.8 Variation in Protein Structure Is the Basis of Biological Diversity 254
- 13.9 Proteins Function in Many Diverse Roles 257

CASE STUDY: Crippled ribosomes 258

Insights and Solutions 259

Problems and Discussion Questions 259

14 Gene Mutation, DNA Repair, and Transposition 261

14.1 Gene Mutations Are Classified in Various Ways 262

14.2 Mutations Can Be Spontaneous or Induced 264

14.3 Spontaneous Mutations Arise from Replication Errors and Base Modifications 265

14.4 Induced Mutations Arise from DNA Damage Caused by Chemicals and Radiation 267

14.5 Single-Gene Mutations Cause a Wide Range of Human Diseases 270

14.6 Organisms Use DNA Repair Systems to Counteract Mutations 271

14.7 The Ames Test Is Used to Assess the Mutagenicity of Compounds 276

14.8 Transposable Elements Move within the Genome and May Create Mutations 277

CASE STUDY: An unexpected diagnosis 281

Insights and Solutions 282

Problems and Discussion Questions 283

15 Regulation of Gene Expression in Bacteria 285

15.1 Bacteria Regulate Gene Expression in Response to Environmental Conditions 286

15.2 Lactose Metabolism in *E. coli* Is Regulated by an Inducible System 286

15.3 The Catabolite-Activating Protein (CAP) Exerts Positive Control over the *lac* Operon 292

15.4 The Tryptophan (*trp*) Operon in *E. coli* Is a Repressible Gene System 293

■ EVOLVING CONCEPT OF THE GENE 295

15.5 RNA Plays Diverse Roles in Regulating Gene Expression in Bacteria 295

15.6 CRISPR-Cas Is an Adaptive Immune System in Bacteria 297

CASE STUDY: MRSA in the National Football League (NFL) 299

Insights and Solutions 300

Problems and Discussion Questions 300

16 Regulation of Gene Expression in Eukaryotes 302

16.1 Organization of the Eukaryotic Cell Facilitates Gene Regulation at Several Levels 303

16.2 Eukaryotic Gene Expression Is Influenced by Chromatin Modifications 304

16.3 Eukaryotic Transcription Initiation Requires Specific *Cis*-Acting Sites 305

16.4 Eukaryotic Transcription Initiation Is Regulated by Transcription Factors That Bind to *Cis*-Acting Sites 307

16.5 Activators and Repressors Interact with General Transcription Factors and Affect Chromatin Structure 309

16.6 Regulation of Alternative Splicing Determines Which RNA Spliceforms of a Gene Are Translated 310

16.7 Gene Expression Is Regulated by mRNA Stability and Degradation 313

16.8 Noncoding RNAs Play Diverse Roles in Posttranscriptional Regulation 315

16.9 mRNA Localization and Translation Initiation Are Highly Regulated 317

16.10 Posttranslational Modifications Regulate Protein Activity 318

EXPLORING GENOMICS

Tissue-Specific Gene Expression 319

CASE STUDY: A mysterious muscular dystrophy 320

Insights and Solutions 320

Problems and Discussion Questions 321

17 Recombinant DNA Technology 323

17.1 Recombinant DNA Technology Began with Two Key Tools: Restriction Enzymes and Cloning Vectors 324

17.2 DNA Libraries Are Collections of Cloned Sequences 329

17.3 The Polymerase Chain Reaction Is A Powerful Technique for Copying DNA 331

17.4 Molecular Techniques for Analyzing DNA and RNA 333

17.5 DNA Sequencing Is the Ultimate Way to Characterize DNA at the Molecular Level 335

17.6 Creating Knockout and Transgenic Organisms for Studying Gene Function 338

17.7 Genome Editing with CRISPR-Cas 341

EXPLORING GENOMICS

Manipulating Recombinant DNA: Restriction Mapping 344

CASE STUDY: Ethical issues and genetic technology 344

Insights and Solutions 345

Problems and Discussion Questions 345

18 Genomics, Bioinformatics, and Proteomics 347

18.1 Whole-Genome Sequencing Is Widely Used for Sequencing and Assembling Entire Genomes 348

18.2 DNA Sequence Analysis Relies on Bioinformatics Applications and Genome Databases 349

- 18.3 The Human Genome Project Revealed Many Important Aspects of Genome Organization in Humans **353**
- 18.4 The "Omics" Revolution Has Created a New Era of Biological Research **355**

■ EVOLVING CONCEPT OF THE GENE **359**

- 18.5 Comparative Genomics Provides Novel Information about the Human Genome and the Genomes of Model Organisms **360**
- 18.6 Metagenomics Applies Genomics Techniques to Environmental Samples **362**
- 18.7 Transcriptome Analysis Reveals Profiles of Expressed Genes in Cells and Tissues **364**
- 18.8 Proteomics Identifies and Analyzes the Protein Composition of Cells **366**
- 18.9 Synthetic Genomes and the Emergence of Synthetic Biology **370**

■ GENETICS, ETHICS, AND SOCIETY

Privacy and Anonymity in the Era of Genomic Big Data **372**

■ EXPLORING GENOMICS

Contigs, Shotgun Sequencing, and Comparative Genomics **372**

CASE STUDY: Your microbiome may be a risk factor for disease **373**

Insights and Solutions **373**

Problems and Discussion Questions **374**

19 The Genetics of Cancer **376**

- 19.1 Cancer Is a Genetic Disease at the Level of Somatic Cells **377**
- 19.2 Cancer Cells Contain Genetic Defects Affecting Genomic Stability, DNA Repair, and Chromatin Modifications **379**
- 19.3 Cancer Cells Contain Genetic Defects Affecting Cell-Cycle Regulation **381**
- 19.4 Proto-oncogenes and Tumor-suppressor Genes Are Altered in Cancer Cells **383**
- 19.5 Cancer Cells Metastasize and Invade Other Tissues **385**
- 19.6 Predisposition to Some Cancers Can Be Inherited **385**
- 19.7 Environmental Agents Contribute to Human Cancers **386**

■ GENETICS, ETHICS, AND SOCIETY

Breast Cancer: The Ambiguities and Ethics of Genetic Testing **389**

CASE STUDY: Cancer-killing bacteria **389**

Insights and Solutions **390**

Problems and Discussion Questions **391**

20 Quantitative Genetics and Multifactorial Traits **392**

- 20.1 Quantitative Traits Can Be Explained in Mendelian Terms **393**

- 20.2 The Study of Polygenic Traits Relies on Statistical Analysis **395**
- 20.3 Heritability Values Estimate the Genetic Contribution to Phenotypic Variability **398**
- 20.4 Twin Studies Allow an Estimation of Heritability in Humans **402**
- 20.5 Quantitative Trait Loci Are Useful in Studying Multifactorial Phenotypes **404**

CASE STUDY: A chance discovery **408**

■ GENETICS, ETHICS, AND SOCIETY

Rice, Genes, and the Second Green Revolution **408**

Insights and Solutions **409**

Problems and Discussion Questions **410**

21 Population and Evolutionary Genetics **412**

- 21.1 Genetic Variation Is Present in Most Populations and Species **413**
- 21.2 The Hardy-Weinberg Law Describes Allele Frequencies and Genotype Frequencies in Population Gene Pools **415**
- 21.3 The Hardy-Weinberg Law Can Be Applied to Human Populations **417**
- 21.4 Natural Selection Is a Major Force Driving Allele Frequency Change **420**
- 21.5 Mutation Creates New Alleles in a Gene Pool **424**
- 21.6 Migration and Gene Flow Can Alter Allele Frequencies **425**
- 21.7 Genetic Drift Causes Random Changes in Allele Frequency in Small Populations **426**
- 21.8 Nonrandom Mating Changes Genotype Frequency but Not Allele Frequency **427**
- 21.9 Speciation Can Occur through Reproductive Isolation **428**
- 21.10 Phylogeny Can Be Used to Analyze Evolutionary History **431**

■ GENETICS, ETHICS, AND SOCIETY

Tracking Our Genetic Footprints out of Africa **434**

CASE STUDY: A tale of two Olivias **435**

Insights and Solutions **436**

Problems and Discussion Questions **436**

■ SPECIAL TOPICS IN MODERN GENETICS 1

Epigenetics **439**

- ST 1.1 Molecular Alterations to the Genome Create an Epigenome **439**
- ST 1.2 Epigenetics and Monoallelic Gene Expression **442**
- ST 1.3 Epigenetics and Cancer **444**
- ST 1.4 Epigenetic Traits Are Heritable **446**
- ST 1.5 Epigenome Projects and Databases **448**

SPECIAL TOPICS IN MODERN GENETICS 2

Genetic Testing 450

- ST 2.1 Testing for Prognostic or Diagnostic Purposes 450
- ST 2.2 Prenatal Genetic Testing to Screen for Conditions 450
- BOX 1 Recommended Uniform Screening Panel 451
- ST 2.3 Genetic Testing Using Allele-Specific Oligonucleotides 453
- ST 2.4 Microarrays for Genetic Testing 455
- ST 2.5 Genetic Analysis of Individual Genomes by DNA Sequencing 457
- BOX 2 Undiagnosed Diseases Network 458
- BOX 3 Genetic Analysis for Pathogen Identification During Infectious Disease Outbreaks 458
- ST 2.6 Genome-Wide Association Studies Identify Genome Variations That Contribute to Disease 461
- ST 2.7 Genetic Testing and Ethical, Social, and Legal Questions 463

SPECIAL TOPICS IN MODERN GENETICS 3

Gene Therapy 468

- ST 3.1 What Genetic Conditions Are Candidates for Treatment by Gene Therapy? 468
- ST 3.2 How Are Therapeutic Genes Delivered? 469
- BOX 1 ClinicalTrials.gov 469
- ST 3.3 The First Successful Gene Therapy Trial 472
- ST 3.4 Gene Therapy Setbacks 472
- ST 3.5 Recent Successful Trials by Conventional Gene Therapy Approaches 473
- ST 3.6 Genome-Editing Approaches to Gene Therapy 475
- ST 3.7 Future Challenges and Ethical Issues 479
- BOX 2 Glybera: The First Commercial Gene Therapy to be Approved in the West Lasted Only Five Years 480
- BOX 3 Gene Doping for Athletic Performance? 481

SPECIAL TOPICS IN MODERN GENETICS 4

Advances in Neurogenetics: The Study of Huntington Disease 482

- ST 4.1 The Search for the Huntington Gene 482
- BOX 1 George Huntington and His Namesake Disease 483
- ST 4.2 The *HTT* Gene and Its Protein Product 484
- ST 4.3 Molecular and Cellular Alterations in Huntington Disease 485
- ST 4.4 Transgenic Animal Models of Huntington Disease 487
- ST 4.5 Cellular and Molecular Approaches to Therapy 488

SPECIAL TOPICS IN MODERN GENETICS 5

DNA Forensics 491

- ST 5.1 DNA Profiling Methods 491
- BOX 1 The Pitchfork Case: The First Criminal Conviction Using DNA Profiling 492
- ST 5.2 Interpreting DNA Profiles 496
- ST 5.3 Technical and Ethical Issues Surrounding DNA Profiling 497
- BOX 2 The Kennedy Brewer Case: Two Bite-Mark Errors and One Hit 498
- BOX 3 A Case of Transference: The Lukis Anderson Story 498

SPECIAL TOPICS IN MODERN GENETICS 6

Genetically Modified Foods 500

- ST 6.1 What Are GM Foods? 500
- BOX 1 The Tale of GM Salmon—Downstream Effects? 502
- ST 6.2 Methods Used to Create GM Plants 503
- ST 6.3 GM Foods Controversies 506
- BOX 2 The New CRISPR Mushroom 506
- ST 6.4 The Future of GM Foods 508

SPECIAL TOPICS IN MODERN GENETICS 7

Genomics and Precision Medicine 510

- ST 7.1 Pharmacogenomics 510
- BOX 1 Preemptive Pharmacogenomic Screening: The PGEN4Kids Program 512
- ST 7.2 Precision Oncology 513
- BOX 2 Precision Cancer Diagnostics and Treatments: The Lukas Wartman Story 514
- BOX 3 Cell Types in the Innate and Adaptive Immune Systems 515
- BOX 4 Steps in Cytotoxic T-cell Recognition, Activation, and Destruction of Cancer Cells 516
- ST 7.3 Precision Medicine and Disease Diagnostics 518
- ST 7.4 Technical, Social, and Ethical Challenges 518
- BOX 5 Beyond Genomics: Personal Omics Profiling 519

APPENDIX Solutions to Selected Problems and Discussion Questions A-1

GLOSSARY G-1

CREDITS C-1

INDEX I-1