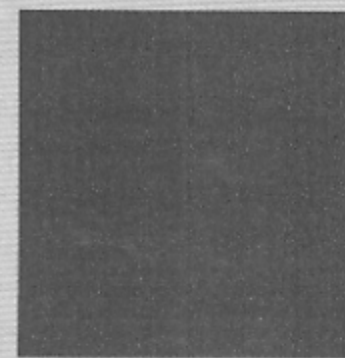


Contents



1 Biology: What Is the Study of Life? 1

–Vignette 1–April 26, 2011

–Vignette 2–November 7, 2021

–Vignette 2–July 17, 2026

1.1 Why Study Biology? 3

Biology Is Relevant, 3

Biology Can Be Controversial, 6

1.2 What Is Biology? 6

What Is Life? 6

Biology Is a Branch of Science, 7

Biology Is Integrated with Other Sciences, 8

What Are the Major Theories of Biology? 9

1.3 How Is Biology Studied? 11

The Scientific Method in Biology, 12

Where Are We Now? 16

2 Evolution: Why Are There So Many Living Things? 19

2.1 Where Did the Idea of Evolution Come From? 20

The Idea of Evolution Preceded Darwin, 20

Even as a Child, Darwin Was Interested in Biology, 22

Many of Darwin's Ideas About Biology Were Shaped by a Voyage Around the World, 23

Some of Darwin's Contemporaries Came to the Same Conclusions, 24

Darwin and Wallace Were the Fathers of Evolution and Pioneers in Methodology, 25

❖❖ Piecing It Together, 25

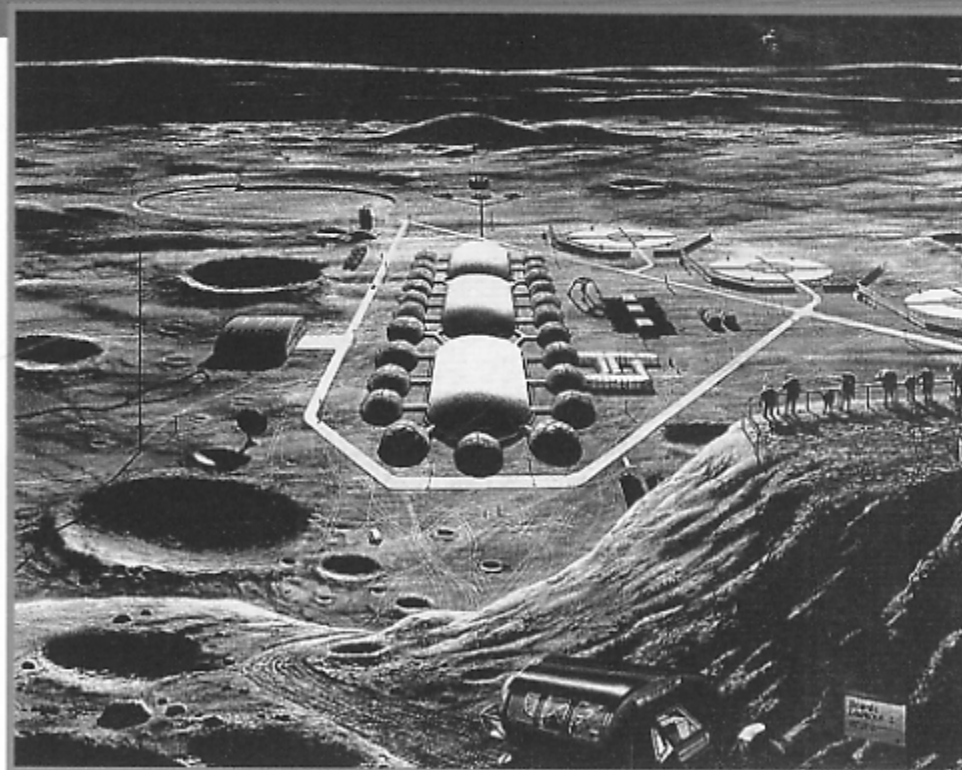
2.2 How Did Darwin Account for Species? 25

First Observation: Populations Have the Potential to Increase Exponentially, 26

Second Observation: Populations Are Fairly Constant in Size, 28

Third Observation: Natural Resources Are Limited, 28

Deduction One: Only Some Organisms Survive. There is a Struggle for Existence among Individuals in a Population, 28



Fourth Observation: There Is Variation within Individuals of a Population and Variations Are Inherited, 29

Deduction Two: Individuals with Favorable Variations Are More Likely to Survive and Reproduce, 30

Deduction Three: Accumulation of Variation over Many Generations Is Evolution, 31

❖❖ Piecing It Together, 33

2.3 How Does the Process of Evolution Work? 34

A Great Deal of Indirect Evidence Supports the Theory of Evolution, 34

Speciation May Occur When Populations Become Isolated, 38

Can Speciation Occur between Populations Whose Ranges Overlap? 42

Let's Take a Look at Darwin's Finches, 44

And What about Humans? 47

❖❖ Piecing It Together, 48

2.4 Are There Patterns in Evolution? 49

Unrelated Organisms Living in Similar Environments Sometimes Evolve Similar Characteristics, 49

Closely Related Species May Become More and More Different, 50

Adaptive Radiation Is an Extreme Example of Divergent Evolution, 51

The Evolution of One Species May Influence the Evolution of Another, 52

Darwin Described Evolution as a Slow and Gradual Process, 52

Evolution May Occur Much More Rapidly than Previously Thought, 52

Evolution Does Not Always Occur, 53

❖❖ *Piecing It Together, 55*

2.5 How Well Was the Theory of Evolution Accepted? 56

After It Was Published, Darwin's Theory Was Hotly Debated, 56

After Darwin's Death, Debates Continued, 58

❖❖ *Piecing It Together, 59*

Where Are We Now? 59

3 Mendelian Genetics: How Are Traits Inherited? 61

3.1 How Are Traits Passed from Generation to Generation? 62

Mendel Discovered That Traits Are Inherited in Discrete Units, 63

Dominant Traits Mask the Presence of Recessive Alleles, 67

Mendel's Observations Are Widely Applicable, 68

Alleles Are Randomly Donated from Parents to Offspring, 71

Mendel's Factors Can Act Independently ... Sometimes, 72

Chance Determines Which Alleles an Individual Inherits, 75

❖❖ *Piecing It Together, 78*

3.2 Why Aren't Members of the Same Species Identical? 78

Independent Assortment Is an Important Source of Variety, 79

Mutations Are Another Source of Genetic Variety, 80

❖❖ *Piecing It Together, 81*

3.3 Do Mendel's Laws Always Apply? 82

Mendel's Laws Are Extended by Experimental Evidence, 82

Mendel's Work Generated New Fields of Inquiry, 87

❖❖ *Piecing It Together, 87*

Where Are We Now? 88

4 Cells: What Are the Building Blocks of Life? 83

4.1 What Is the Cellular Nature of Life? 92

Microscopes Made Possible the Discovery of Cells, 92

The Cell Theory Was Proposed in the Early 1800s, 94

❖❖ *Piecing It Together, 95*

4.2 Where Do Cells Come From? 95

The Cell Theory Contradicted the Theory of Spontaneous Generation, 95

A Series of Brilliant Experiments Settled the Issue, 96

A Brief Look at Viruses, 98

❖❖ *Piecing It Together, 100*

4.3 What Are the Major Kinds of Cells? 100

Prokaryotic Cells Have Few Internal Parts, 101

Eukaryotic Cells Have Numerous Internal Structures, 103

❖❖ *Piecing It Together, 108*

4.4 What Is the Nature of Cellular Membranes? 108

Cellular Membranes Are Flexible Bilayers, 109

Materials Enter and Leave Cells through their Membranes, 110

❖❖ *Piecing It Together, 114*

Where Are We Now? 115

5 Chromosomes: Where Are the Genes Found? 119

5.1 What Cellular Structure Holds the Genetic Information? 120

Chromosomes Are Apportioned to Daughter Cells During Mitosis, 120

Chromosomes Come in Matched Pairs, 123

Meiosis Is Cell Division That Reduces the Chromosome Number, 126

Cell Division Is Part of the Cell Cycle, 129

The Cell Cycle Is Highly Regulated, 131

❖❖ *Piecing It Together, 132*

5.2 Why Do Some Genetic Traits Tend to Travel Together? 133

Chromosomes, Not Genes, Follow the Law of Independent Assortment, 134

Chromosomes Can Exchange Parts during Meiosis, 136

Bits of Chromosomes Can Move, 137

❖❖ *Piecing It Together, 138*

5.3 What Is the Chemical Nature of the Gene? 139

Chromosomes Are Both Protein and Nucleic Acid, 139

DNA Is the Genetic Material, 140

Further Evidence for the Genetic Role of DNA, 141

❖❖ *Piecing It Together, 144*

Where Are We Now? 144

6 Molecular Biology: What Is DNA and How Does It Work? 148

6.1 What Is the Structure of DNA? 148

DNA's Structure Must Be Compatible with Its Four Roles, 148

DNA Is a Double Helix, 149

❖❖ Piecing It Together, 153

6.2 How Does DNA Make Copies of Itself? 153

DNA Replication Precedes Cell Division, 153

❖❖ Piecing It Together, 153

6.3 How Is the Information in DNA Expressed? 157

DNA Encodes the Information to Make Proteins, 158

RNA Acts as an Intermediary, 158

RNA Is Synthesized in Transcription, 161

Proteins Are Synthesized in Translation, 163

Three RNA Nucleotides Code for One

Amino Acid, 166

❖❖ Piecing It Together, 168

6.4 What Makes Cells Different from Each Other? 169

Prokaryotes Regulate Genetic Expression Mostly at Transcription, 169

Eukaryotes Regulate Genetic Expression at Many Different Levels, 170

❖❖ Piecing It Together, 170

6.5 How Does DNA Change over Time? 172

Some Mutations Involve Whole Chromosomes, 172

Some Mutations Involve Single DNA Bases, 175

❖❖ Piecing It Together, 176

Where Are We Now? 177

7 Biotechnology: How Do We Use What We Know About Life? 179

7.1 What Tools Are in the Biotechnology Toolbox? 179

Bacteria and Viruses Play a Central Role in Biotechnology, 180

Molecular Tools Are Used to Manipulate DNA, 182

❖❖ Piecing It Together, 195

7.2 Why Sequence the Human Genome? 196

The Human Genome Project Has Short-Term and Long-Term Goals, 196

What We Have Learned from the Human Genome, 197

The HGP Has Raised Ethical, Legal, and Social Issues, 199

❖❖ Piecing It Together, 202

7.3 How Do We Use Biotechnology? 202

Gene Therapy and Designer Drugs, 202

DNA Is Used in the Courtroom, 205

Biotechnology Is Used on the Farm, 207

Can Biotechnology Save the Environment? 209

❖❖ Piecing It Together, 210

7.4 What Are the Risks of Biotechnology and How Should We Address Them? 211

Some Question the Safety of Biotechnology, 211

Some Question the Ethics of Biotechnology, 212

❖❖ Piecing It Together, 213

Where Are We Now? 214

8 Population Genetics: How Do Genes Move through Time and Space? 217

8.1 How Do We Characterize Variation? 218

Variation Can Be Smooth or Discontinuous, 218

Frequency Diagrams Illustrate Variation, 220

Continuous Variation Is Determined by Two or More Genes, 223

❖❖ Piecing It Together, 224

8.2 How Do Populations Differ? 225

Populations Are Collections of Alleles, 226

Alleles Occur at Certain Frequencies, 226

The Hardy-Weinberg Principle Relates Genotypes and Allelic Frequencies, 227

❖❖ Piecing It Together, 230

8.3 How Can Allelic Frequencies Change over Time? 230

Natural Selection Changes Allelic Frequencies, 231

Selection Can Favor Any Part of the Range of Phenotypes, 234

Some Changes in Allelic Frequency Are Random, 235

❖❖ Piecing It Together, 243

Where Are We Now? 244

9 Biodiversity: How Diverse Is Life? 247

9.1 How Did Life Originate? 248

Early Speculations on the Origins of Life Lacked Experimental Evidence, 250

Early Experiments Spontaneously Produced Organic Compounds, 250

The Next Step Was to Move Beyond Isolated Carbon-Based Compounds to Cells, 252

❖❖ Piecing It Together, 254

9.2 What Were the Major Milestones in Earth's Evolving Biodiversity? 254

The First Cells Evolved into the Different Cell Types We See Today, 257

Simple Cells Evolved into More Complex Cells, 256

Single-Celled Organisms Evolved into Multicelled Organisms, 256

The Evolution of Animals Involved Several Milestones, 256

❖❖ Piecing It Together, 259

9.3 How Do Biologists Keep Track of So Many Species? 260

Prior to Darwin, Classification Was Concerned with Describing "Natural Order," 261

After Darwin and Mendel, Emphasis Shifted to the Ancestry of Species, 263

Today, Modern Tools Are Yielding Direct Evidence of Evolutionary Relationships between Species, 263

❖❖ Piecing It Together, 266

9.4 How Does the System Work? 266

At First, There Were Thought To Be Only Two Kingdoms; Now There Are at Least Five, 266

Within Each Kingdom, There Are Many Species Requiring Additional Categories, 268

❖❖ Piecing It Together, 272

9.5 How Diverse Is Life on Earth? 272

A Brief Look at Archaea and Bacteria Domains, 273

A Brief Look at Domain Eukarya, Kingdom Protista, 276

A Brief Look at Domain Eukarya, Kingdom Fungi, 280

A Brief Look at Domain Eukarya, Kingdom Plantae, 284

A Brief Look at Domain Eukarya, Kingdom Animalia, 286

❖❖ Piecing It Together, 294

Where Are We Now? 295

10 Bioenergetics: How Do Organisms Acquire and Use Energy? 297

10.1 How Does Energy Behave in the Universe? 298

The Energy of Life Is Not Unique, 298

Energy Can Take Different Forms, But It Is Always Conserved, 298

In Any Energy Transformation, Entropy Increases, 299

❖❖ Piecing It Together, 301

10.2 How Is Energy Transformed in the Biosphere? 301

Animal Respiration, Like Fire, Is Oxidation, 301

Metabolism Is Both Efficient and Highly Specific, 304

ATP Is the Energy Currency of Life, 307

Other Nucleotide-Based Compounds Shuttle Hydrogen, 308

❖❖ Piecing It Together, 311

10.3 How Do Organisms Use Energy? 311

Cellular Respiration Occurs in Three Stages, 312

Glycolysis Is the Anaerobic Stage of Cellular Respiration, 313

The Krebs Cycle and Electron Transport Provide Energy Aerobically, 316

ATP Is Made Using Energy from a Proton Gradient, 319

❖❖ Piecing It Together, 321

10.4 How Do Organisms Acquire Energy? 322

Photosynthesis Uses Light Energy to Make Food, 322

Pigments Absorb the Energy of Light, 323

Light Reactions Make ATP and NADPH, 325

The Calvin-Benson Cycle Uses CO₂, ATP, and NADPH to Make Food, 328

❖❖ Piecing It Together, 330

Where Are We Now? 330

11 Animal Physiology: How Do Organisms Respond to Change? 333

11.1 What Are the Underlying Principles of Physiology? 334

The Cells of Multicellular Organisms Are Hierarchically Organized, 335

Multicellular Organisms Are More Than the Sum of Their Parts, 337

Multicellular Organisms Function Best within Stable Internal Environments, 337

Feedback Systems Control Many Physiological Processes, 338

Some Additional Points to Keep In Mind, 339

❖❖ Piecing It Together, 341

11.2 How Do Organisms Obtain Information about Their Environment? 342

Microbes and Fungi May Monitor and Respond to Their Environments Chemically, 342

Hormones Are Important Chemically Based Monitor and Control Systems in Animals, 343

In Addition to Endocrine Systems, Animals Have Nervous Systems, 343

❖❖ Piecing It Together, 344

11.3 How Do Organisms Acquire and Process Nutrients and Wastes? 346

Bacteria, Protists, and Fungi Excrete Enzymes to Break Down Complex Compounds and Obtain Nutrients, 346

Multicellular Animals Have Digestive Systems with Which to Obtain Nutrients, 346

Animals Use Respiration to Obtain the Gases They Need, 349

Circulatory Systems Move Nutrients, Gases, and Other Materials through the Bodies of Complex Animals, 352

Animals Must Maintain Proper Water Balance, 354
Organisms Must Get Rid of Metabolic Wastes, 356

❖❖ Piecing It Together, 358

11.4 How Do Organisms Move? 358

Microbes Evolved Thick Cell Walls and Special Organelles for Movement, 359

Animal Movements Involve Interactions between Muscles and Skeletons, 360

❖❖ Piecing It Together, 362

11.5 How Do Organisms Reproduce? 363

The Most Common Method of Reproduction Is Asexual, 363

Sexual Reproduction Evolved among Bacteria, Protists, and Fungi, 364

Sexual Reproduction in Water Is Relatively Easy, 365

Many Animals Successfully Reproduce on Land, 367

After Fertilization, Organisms Develop and Grow, 369

❖❖ Piecing It Together, 372

Where Are We Now? 373

12 Human Physiology: How Does the Human Body Work? 375

12.1 How Do the Parts of the Human Body Communicate? 377

The Nervous System Provides Rapid Communication, 377

Hormones Coordinate Slower, Longer-Lasting Processes, 385

❖❖ Piecing It Together, 390

12.2 How Do Humans Acquire and Process Nutrients and Get Rid of Wastes? 391

Food Enters the Body through the Digestive System, 391

Oxygen and Carbon Dioxide Are Exchanged in the Lungs, 398

The Cardiovascular System Moves Materials throughout the Body, 401

Metabolic Wastes, Water, and Salts Are Processed by the Kidneys, 406

❖❖ Piecing It Together, 409

12.3 How Does the Human Body Move? 410

The Skeleton Provides the Framework, 410

Muscles Cause Movement, 411

❖❖ Piecing It Together, 415

12.4 How Do Humans Reproduce? 415

Gametes Are Produced in Gonads, 416

The Reproductive Male, 417

The Reproductive Female, 418

❖❖ Piecing It Together, 421

12.5 How Does the Body Fight Disease? 421

The Immune System Is Integrated throughout the Body, 422

Nonspecific Responses Are the Second Line of Defense, 424

Acquired Immune Responses Recognize Familiar Invaders, 425

❖❖ Piecing It Together, 427

Where Are We Now? 428

13 Plant Form and Function: How Do Plants Live in the World? 431

13.1 What Important Events Define the History of Plant Life? 432

Photosynthesis Changed the World, 432

Eukaryotic Cells and Multicellularity Enabled Plants to Diversify, 434

Plants Moved from Water to Land, 436

Vascular Plants Dominate the Terrain, 438

❖❖ Piecing It Together, 441

13.2 What Do Plants Need and How Do They Get It? 441

Plants Need Light, 441

Plants Need Gases, 443

Plants Need Water, 445

Plants Need Nitrogen and Other Nutrients, 447

❖❖ Piecing It Together, 450

13.3 How Do Higher Plants Transport Substances and Support Themselves? 451

Translocation Occurs in Conducting Tissues, 451

Transpiration Moves Water and Minerals, 453

Plants Need Mechanical Support, 455

❖❖ Piecing It Together, 456

13.4 How Do Plants Grow, Reproduce, and Develop? 456

Plant Growth, 456

Plants Have Hormones, 460

Plants Reproduce Sexually, 464

❖❖ Piecing It Together, 469

Where Are We Now? 470

14 Behavior: How Do Animals Interact with Other Animals? 473

14.1 How Is Animal Behavior Studied? 474

The History of Animal Behavior, 475

Controversy between Nature and Nurture Split Early Investigators of Animal Behavior, 477

Animal Learning Illustrates the Importance of Nurture, 480

❖❖ Piecing It Together, 482

14.2 How Is Animal Behavior Related to the Other Branches of Biology? 482

The Genetics of Behavior, 483

The Evolution of Behavior, 484

The Physiology of Behavior, 486

❖❖ Piecing It Together, 487

14.3 How Do Individual Animals Behave? 487

- Animals Move through Space, 488
- Animals Forage for Food, 490
- Animals Avoid Becoming Food, 492
- Animals Reproduce, 494

❖❖ *Piecing It Together, 499***14.4 How Do Groups of Animals Behave? 500**

- Some Animals Live in Groups While Others Live Alone, 501
- Animals Communicate, Especially in Groups, 501
- Some Animals Appear to Behave Altruistically, 504

❖❖ *Piecing It Together, 506*

Where Are We Now? 506

15 Population Ecology: How Do Organisms Interact to Form Populations? 509**15.1 What Is Ecology? 509**

- Ecology Is a Branch of Biology, 510
- Ecology Grew from Natural History, 512

❖❖ *Piecing It Together, 515***15.2 How Do Ecologists Study Populations? 516**

- The Study of Populations Has Been One of Ecology's Major Tasks, 516
- The Size of a Population Is Determined by Natality, Mortality, Immigration, and Emigration, 517
- Population Characteristics Are Expressed in a Variety of Ways, 518

❖❖ *Piecing It Together, 520***15.3 How Do Populations Grow? 520**

- Some Populations Grow Exponentially, 521
- Growth of Most Populations Follows an S-shaped Curve, 522
- A Variety of Factors Limit Population Growth, 524
- K-Selection and r-Selection Are Two Patterns of Population Growth, 525
- Graphs of Age Structure Allow Predictions of Future Population Growth, 525
- Populations Differ in Their Longevity and Survivorship Patterns, 527

❖❖ *Piecing It Together, 529***15.4 How Do Populations Interact? 530**

- When Populations Compete, Both Are Harmed, 531
- In Predator and Prey Interactions, One Population Benefits at the Expense of the Other, 532
- Some Populations Form Intimate Associations, 538

❖❖ *Piecing It Together, 540*

Where Are We Now? 540

16 Ecology: How Do Organisms Interact with Their Environments? 545**16.1 What Is an Ecosystem? 546**

- An Ecosystem Comprises Interacting Environmental Components, 546
- Ecosystems Are Definable, Open, and Dynamic, 547

❖❖ *Piecing It Together, 548***16.2 How Does the Physical Environment Affect Organisms? 548**

- The Physical Environment Limits Where Organisms Live, 549
- Light, Temperature, and Wind Affect Organisms, 550
- The Physical Environment Supports Life through the Cycling of Water and Nutrients and the Flow of Energy, 553

❖❖ *Piecing It Together, 555***16.3 How Are Ecosystems Organized and How Do They Differ? 555**

- Biological Communities Are Organized in Trophic Levels, 555
- Some Ecosystems Are Organized Vertically, 560
- Biological Communities Change from Time to Time and Differ from Place to Place, 562
- Biomes Display Global-Scale Variations in Biological Communities, 566

❖❖ *Piecing It Together, 566***16.4 How Do Human Activities Affect the Environment? 568**

- Humans Are Dominant in Today's Ecosystems, 568
- Science Plays Only a Limited Role in Solving Environmental Problems, 569
- Can We Come to Grips with the Growth of the Human Population? 570
- Are Human Activities Poisoning the Earth? 574
- Will Human-Caused Global Warming Change Earth's Climate? 577

❖❖ *Piecing It Together, 579*

Where Are We Now? 579

Appendix A: A Brief Review of Basic Chemistry, 582**CR.1 What Is Matter Made of? 582****CR.2 How Are the Parts of the Atom Arranged? 585****CR.3 How Do Atoms Form Molecules and Compounds? 586****CR.4 What Are the Properties of Water? 587**

- Water's Three States, 588
- Surface Tension, 588
- Capillary Action, 589
- Specific Heat, 590

Heat of Vaporization, 591
Expandability of Freezing Water, 592
Water Is the "Universal Solvent," 592
Acids and Bases, 593

Appendix B: A Brief Review of the Chemistry of Life, 595

CR.5 What Are the Molecules of Life? 595
Hydrocarbons, 596

Carbohydrates, 597
Lipids, 598
Proteins, 600
Nucleic Acids, 602

Glossary, G1

Photo Credits P1

CD Index, CD1

Index, I1