

Principles of **Life**

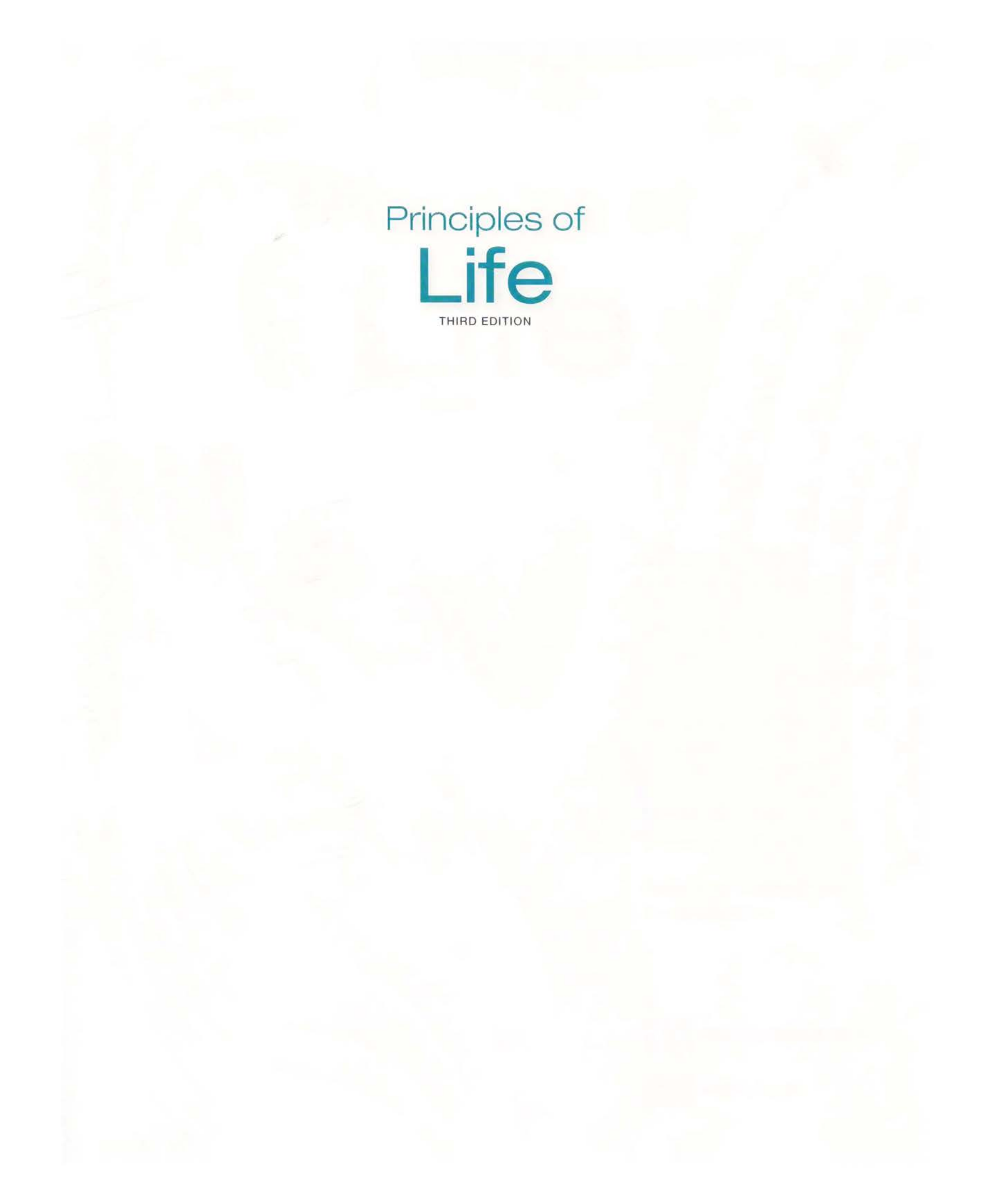
THIRD EDITION

An underwater photograph showing a group of seals swimming in a kelp forest. The water is clear and blue, with sunlight filtering through the kelp leaves and stems. The seals are in various positions, some swimming towards the camera and others away. The kelp is green and yellow, with some small, round fruits visible.

David M. Hillis
Mary V. Price
Richard W. Hill
David W. Hall
Marta J. Laskowski



To their surprise, scientists have discovered that the health of a marine “forest” of giant kelp (brown algae) is tied to that of the fish-eating sea lions shown here swimming through the kelp. This discovery illustrates a fundamental principle: life consists of systems of interacting, interdependent parts on a hierarchy of scales from molecules to cells, organs, organisms, populations, communities, and ecosystems. How do sea lions influence kelp? Killer whales eat sea lions, and when sea lions are scarce, the whales turn to sea otters. Sea otters eat sea urchins, which eat kelp, photosynthetic organisms that capture solar energy and store it in the chemical bonds that feed living things in the kelp ecosystem. Kelp forests are dynamic systems: when whales are common and otters are rare, urchins flourish and decimate kelp, creating “barrens” devoid of the diversity of life that kelp forests support; when whales move on to better hunting grounds, otters flourish, urchins decline, and kelp forests return.



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Principles of
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Principles of Life, Third Edition

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Address editorial correspondence to:
Oxford University Press, 23 Plumtree Road, Sunderland, MA 01375 U.S.A.

Address orders to:
MPS/W. H. Freeman & Co., Order Department, 16365 James Madison Highway,
U.S. Route 15, Gordonsville, VA 22942 U.S.A.

Examination Copy Information: 1-800-446-8923

Library of Congress Cataloging-in-Publication Data

Names: Hillis, David M., 1958- author.
Title: Principles of life / David M. Hillis, University of Texas at Austin,
Mary V. Price, University of California, Riverside, Richard W. Hill,
Michigan State University, David W. Hall, University of Georgia,
Marta J. Laskowski, Oberlin College.
Description: Third edition. | Sunderland, MA : Oxford University Press, [2019]
Identifiers: LCCN 2018031705 | ISBN 9781319017712 (casebound)
Subjects: LCSH: Biology.
Classification: LCC QH308.2 .P75 2019 | DDC 570.1--dc23
LC record available at <https://lccn.loc.gov/2018031705>

Printed in U.S.A.
First Printing December 2018
Printed by LSC Communications

To all our students. You have taught us, too, and inspired us to write this book.

About the Authors

from left: Mary Price, David Hall,
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DAVID M. HILLIS is the Alfred W. Roark Centennial Professor in Integrative Biology at the University of Texas at Austin, where he also has directed the Center for Computational Biology and Bioinformatics, the Biodiversity Center, and the School of Biological Sciences. Dr. Hillis has taught courses in introductory biology, genetics, evolution, systematics, and biodiversity. He is a member of the National Academy of Sciences and the American Academy of Arts and Sciences. He was awarded a John D. and Catherine T. MacArthur Fellowship, and has served as President of the Society for the Study of Evolution and of the Society of Systematic Biologists. He served on the National Research Council committee that wrote the report *BIO 2010: Transforming Undergraduate Biology Education for Research Biologists*, and currently serves on the Executive Committee of the National Academies Scientific Teaching Alliance.

MARY V. PRICE is Professor of Biology, Emerita, at the University of California, Riverside, and Adjunct Professor in the School of Natural Resources and the Environment at the University of Arizona. In "retirement" she continues to teach, investigate, and publish. Dr. Price has taught, mentored, and published with students at all levels, and particularly enjoys leading field classes in the arid regions of North America and Australia, and the tropical forests of Central America, Africa, and Madagascar. Her research focuses on understanding not only the ecology of North American deserts and mountains, but also on how science really works.

RICHARD W. HILL is Emeritus Professor in the Department of Integrative Biology at Michigan State University and a frequent Guest Investigator at Woods Hole Oceanographic Institution. He is the senior author of the leading textbook on animal physiology. Among the awards he has received are the Outstanding Faculty Award, Meritorious Faculty Award, and election as Fellow of the AAAS. His research interests include: temperature regulation and energetics in birds and mammals, especially neonates; and environmental physiology of marine tertiary sulfonium and quaternary ammonium compounds.



DAVID W. HALL is an Associate Professor of Genetics at the University of Georgia, where he was the recipient of the Sandy Beaver Excellence in Teaching Award in 2013. Recent work includes using mathematical models to address the evolution of meiotic drive, the rate and pattern of molecular evolution in social insects, and early sex chromosome evolution. In the lab, he utilizes different yeast species to study spontaneous mutations using a combination of both mutation-accumulation and adaptation experiments. Since high school, he has been captivated by how the living world works. Like many students, he was initially overwhelmed by the diversity of life, but he came to realize that there are fundamental principles that unite organisms. His interest in determining how these principles shape the diversity of life led him into his research and teaching career.

MARTA J. LASKOWSKI is a Professor in the Biology Department at Oberlin College. Dr. Laskowski has mentored undergraduate students in research and has taught introductory biology, skills-based first year seminars (Feeding the World), plant physiology, and plant development. She heads an effort at Oberlin, funded by the HHMI Inclusive Excellence program, to enhance the climate for and success of a diverse student population in STEM. One of her numerous journal articles resulted in a *Guinness World Record* for the fastest opening flower (*Cornus canadensis*; bunchberry). A college class in developmental biology so captivated her that she decided to focus her research on discovering the intricate sub-cellular interactions that establish the plant root system.



All the new enhancements add not just to the learning experience of the students, but also make teaching this material that much more focused and aligned with something that is emerging as an important standard... A welcome improvement in a biology textbook, designed for both instructors and students, which adopts key pedagogical competencies, wholly aligned with the *Vision and Change* directive."

Kamal Dulai, University of California, Merced



The new toolbox of active learning opportunities integrated into the Third Edition of *Principles of Life* provides numerous opportunities for students and faculty to master *Vision and Change's* Core Competencies. If used creatively, this text contains essential tools for mastering biology."

Justen Whittall, Santa Clara University

Principles of Life, Third Edition

1 Principles of Life



PART 1 CELLS

- 2 Life's Chemistry and the Importance of Water
- 3 Macromolecules
- 4 Cell Structure and Membranes
- 5 Cell Metabolism: Synthesis and Degradation of Biological Molecules
- 6 Cell Signals and Responses



PART 2 GENETICS

- 7 The Cell Cycle and Cell Division
- 8 Inheritance, Genes, and Chromosomes
- 9 DNA and Its Role in Heredity
- 10 From DNA to Protein: Gene Expression
- 11 Regulation of Gene Expression
- 12 Genomes



PART 3 EVOLUTION

- 13 Processes of Evolution
- 14 Reconstructing and Using Phylogenies
- 15* Evolution of Genes and Genomes
- 16 Speciation
- 17 The History of Life on Earth



PART 4 DIVERSITY

- 18 Bacteria, Archaea, and Viruses
- 19 The Origin and Diversification of Eukaryotes
- 20 The Evolution of Plants
- 21 The Evolution and Diversity of Fungi
- 22 Animal Origins and Diversity



PART 5 PLANT FORM AND FUNCTION

- 23 The Plant Body
- 24 Plant Nutrition and Transport
- 25 Plant Growth and Development
- 26 Reproduction of Flowering Plants
- 27 Plants in the Environment



PART 6 ANIMAL FORM AND FUNCTION

- 28 Transformations of Energy and Matter: Nutrition, Temperature, and Homeostasis
- 29* Animals in Their Environments
- 30 Breathing and Circulation
- 31 Neurons, Sense Organs, and Nervous Systems
- 32 Control by the Endocrine and Nervous Systems
- 33 Muscle and Movement
- 34 Animal Reproduction
- 35 Animal Development
- 36 Immunology: Animal Defense Systems
- 37 Animal Behavior



PART 7 ECOLOGY

- 38 Ecological Systems in Time and Space
- 39 Populations
- 40 Interactions within and among Species
- 41 Ecological Communities
- 42 The Global Ecosystem

* = New Chapter

Principles of Life —Tour of the New Edition

Because success as a biologist means more than just succeeding in the first biology course

If you're concerned that the practical skills of biology will be lost when you move on to the next course or take your first step into the "real world," *Principles of Life*, Third Edition lays a solid foundation for later courses and for your career. Expanding on its pioneering concept-driven approach, experimental data-driven exercises, and active learning focus, the new edition introduces features designed to help you master concepts and become skillful at solving biological problems.

Research shows that when students engage with a course, it leads to better outcomes. *Principles of Life*, Third Edition is a holistic solution that has been designed from the ground up to actively engage you and help develop your skills as a biologist.

With its focus on key competencies foundational to biology education and careers, self-guided adaptive learning, and online resources, *Principles of Life* is the resource you need to succeed.

THINK LIKE A SCIENTIST

Quantitative Reasoning **Changes in Earth's physical environment have affected the evolution of life**

Modeling & Simulation

In the experiment shown in Investigation Figure 17.8, body mass of individuals in the experimental populations of *Drosophila* increased (on average) about 2 percent per generation in the high-oxygen environment (although the rate of increase was not constant over the experiment). In the Permian, giant flying insects, such as dragonflies the size of modern hawks, inhabited Earth. Is the rate of increase in body mass

A FOCUS ON SKILLS AND CORE COMPETENCIES

New to this edition, the AAAS *Vision and Change* report's six "core competencies," related to quantitative reasoning, simulation, and communication, are integrated both implicitly throughout the text and explicitly in a new key feature, Think Like a Scientist. TLAS boxes develop these core competencies, and have been designed specifically to teach you the skills you need to become a functional, practical, effective scientist.

ANALYZE THE DATA

After Kashefi and Lovley isolated Strain 121, they examined its growth at various temperatures. The table below shows generation time (time between cell divisions) at nine temperatures.

Temperature (°C)	Generation time (hr)
85	10
90	4
95	3
100	2.5
105	2
110	4
115	6
120	20

A FOCUS ON DATA

Principles of Life has always emphasized the role of research and experimentation in the introductory biology curriculum. You will learn about the scientific method and experimental design, and understand how real research continues to drive our understanding of life on Earth.

Chemiosmotic Mechanism

Examining Mitochondrial Poisons: Cyanide

In your groups, predict what effect HCN would have on the inputs and outputs of these reactions. What will build up, and what will be depleted?

A FOCUS ON ACTIVE LEARNING

Where other texts give lip service to active learning, *Principles of Life* delivers, with an Active Learning Guide and 30 Active Learning Modules ready for classroom delivery. Built around key concepts, the ALMs provide a road map for pre-class work and in-class activities, including Apply the Data exercises, animations, videos, and quizzing directly mapped to in-text concepts and learning objectives.

Principles of Life, Third Edition Content Updates

The Third Edition of *Principles of Life* has not only been revised to be a more effective pedagogical tool, but it has also been updated to reflect the latest research and advances in biology.



PART 1: CELLS

- Increased focus on electronegativity to understand chemical bonding, including polarity, and redox reactions
- Clarified the meaning and role of chemical bond energy
- Increased emphasis on structure as it relates to function
- Improved emphasis on similarities across all organisms at the cellular level
- Reorganized treatment of cell metabolism to focus on underlying principles
- Simplified descriptions of cell signaling pathways to focus on general principles



PART 2: GENETICS

- Increased emphasis of similarities across all organisms for the encoding and expression of genetic information
- Now focused on the differences in initiation, elongation, and termination for replication, transcription, and translation, to prevent common misconceptions
- Focused descriptions of the relationship between genotype and phenotype for clarity
- Clarified coverage of the similarities and differences between meiosis and mitosis
- Updated genomics chapter (Chapter 12) and extended coverage of selfish DNA
- Biotechnology content integrated into other chapters to improve context



PART 3: EVOLUTION

- Integrated coverage of Evo-Devo (evolution and development) into evolution section
- NEW CHAPTER: Chapter 15, Evolution of Genes and Genomes
- New problems that ask you to make and use phylogenetic trees, assess selection, calculate rates of change, and evaluate reproductive isolation
- Updated information on the history of life on Earth



PART 4: DIVERSITY

- Updated information on classifications and phylogeny of life
- Clarified coverage of the similarities and differences of sexual reproduction across major groups of life
- More problems asking you to apply information about the diversity of life to practical situations
- Simplified terminology in explaining the principles surrounding life's diversity



PART 5: PLANT FORM AND FUNCTION

- Added explanations of mechanisms that drive plant development including meristem function and cell identity specification
- Updated information as to how temperature-dependent changes in the dark reversion rates of phytochrome allow plants to sense and respond to temperature
- Added connections between plant physiology and real-world issues such as climate change



PART 6: ANIMAL FORM AND FUNCTION

- NEW CHAPTER: Chapter 29, Animals in Their Environments
- A single unified chapter on breathing and circulation (Chapter 30)
- Twice as many data sets for analysis and discussion
- An emphasis on comparative approaches to ecology throughout these chapters



PART 7: ECOLOGY

- Expanded and updated treatment of the human microbiome as an ecological system
- Streamlined mathematical treatment of the dynamics of ecological populations
- Updated coverage of biogeochemical cycles with latest research findings

Core Competencies

Principles of Life was created to ensure that you gain the knowledge you need from your introductory biology course, and acquire the skills needed to succeed as a life sciences major.

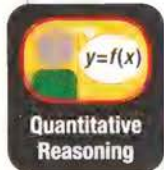
New to this edition, the AAAS *Vision and Change* report's six "core competencies," related to quantitative reasoning, simulation, and communication, are integrated both implicitly throughout the text and explicitly in a new key feature, **THINK LIKE A SCIENTIST**.

NEW! THINK LIKE A SCIENTIST

A major goal of the new edition is to align the text with the *Vision and Change* recommendations, especially as they relate to acquisition of the six core competencies. TLAS boxes explicitly develop these core competencies, and have been designed specifically to teach the skills needed to become a functional, practical, effective scientist. TLAS questions are high-level and aim to have you integrate concepts across the chapter or across chapters, and ask you to *do something*.

NEW

THINK LIKE A SCIENTIST



Changes in Earth's physical environment have affected the evolution of life

In the experiment shown in Investigation Figure 17.8, body mass of individuals in the experimental populations of *Drosophila* increased (on average) about 2 percent per generation in the high-oxygen environment (although the rate of increase was not constant over the experiment). In the Permian, giant flying insects, such as dragonflies the size of modern hawks, inhabited Earth. Is the rate of increase in body mass seen in Investigation Figure 17.8 sufficient to account

for the giant insects of the Permian? How long would it take for giant insect body size to evolve?


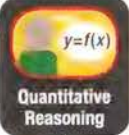




Here you will use quantitative reasoning and a simple model of selection to estimate how quickly insect body size could have evolved in response to higher atmospheric oxygen concentrations.

1. Suppose that the average rate of increase in dragonfly size



NEW

THINK LIKE A SCIENTIST

- 
Process of Science
- 
Quantitative Reasoning
- 
Modeling & Simulation
- 
Interdisciplinary
- 
Science & Society
- 
Communicate & Collaborate



Very Effective—Think Like a Scientist is a great feature and I would assign this as a supplemental assignment. This feature encourages synthesis of material and development of critical-thinking skills around a relevant topic."

—Dr. E. Scott Simpson, PhD, University of Maryland, College Park

Core Competencies



The **TLAS** is great. Wonderful emphasis on critical thinking and application.”

Jennifer A. Metzler, *Ball State University*

NEW

THINK LIKE A SCIENTIST



Forensic phylogeny

Phylogenetic trees are used throughout biology, but only in recent years have they become important for forensic investigations. Here you will explore the relationship between science and society by applying your knowledge of phylogeny to a criminal case.

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A criminal case in Texas charged a defendant with knowingly and intentionally infecting a series of women with HIV. A phylogenetic analysis was used to demonstrate that the defendant transmitted HIV to his victims. (Other evidence was needed to prove knowledge and intent.) In this case, sequences of HIV isolated from the victims and the defendant, together with the closest sequences from an HIV database (the outgroup), were compared and used to construct a phylogenetic tree of the viruses (**FIGURE 14.10**). Viruses from each individual in the case are colored alike on the tree to the right. The labels are the codes for the individuals in the case. All of the individuals labeled CC01–CC08 are known to have engaged in sex; they represent an epidemiological cluster. (In forensic cases, samples are “blinded” to the investigators by assigning numbers to each sample, rather than using people’s names. Only after the conclusions are finalized do other investigators decode the numbers to reveal the results.)

1. Which of the individuals labeled in the tree is consistent with being the source of this infection cluster? Why?
2. Why is the tree inconsistent with any of the other individuals being the source of infection within this cluster?
3. What was the purpose of including an outgroup made up of individuals who were outside the epidemiological cluster?

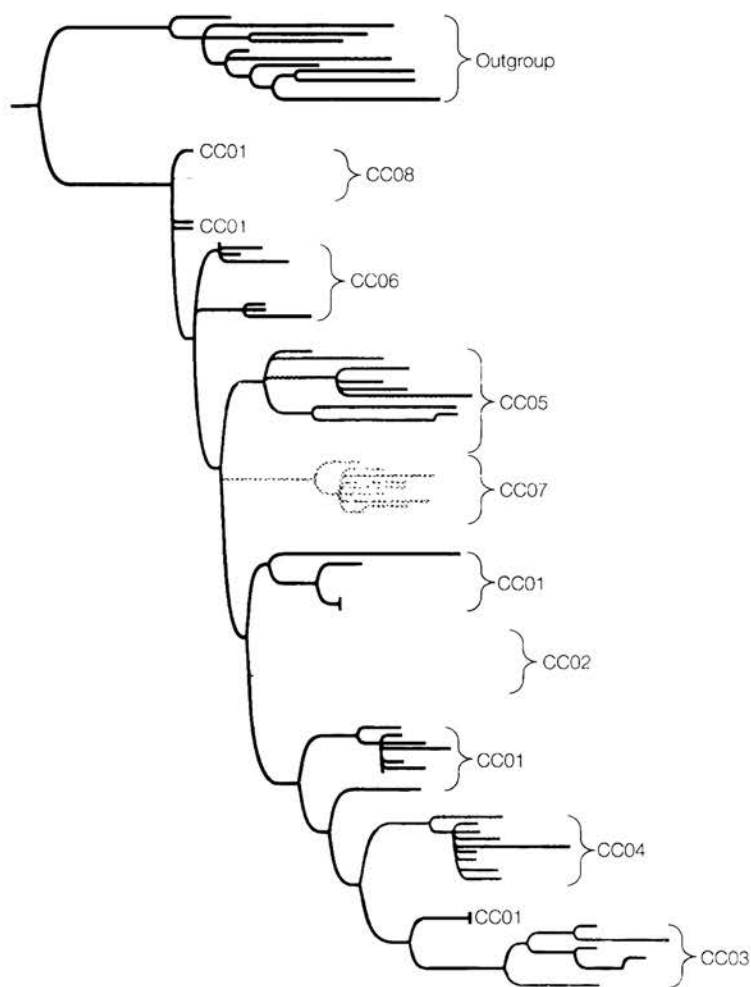


FIGURE 14.10 Forensic Phylogeny (After D. I. Scaduto et al. 2010. *Proc Natl Acad Sci USA* 107: 21242–21247.)

A complete list of the **Think Like a Scientist** boxes is shown on the following pages xii and xiii, along with their related **core competencies**.

Core Competencies

THINK LIKE A SCIENTIST

Chapter	Title	Process of Science	Quantitative Reasoning	Modeling & Simulation	Interdisciplinary	Science & Society	Communicate & Collaborate
2	Climbing the walls	•				•	
3	The origin of the molecules of life on Earth			•			
4	Advances in microscopy have resulted in greater understanding of cell structure and function		•		•		
5	The green Earth	•	•				
6	Identifying and ordering steps in signal transduction pathways	•					
7	Treating cancer	•				•	
8	Coat color inheritance in Labrador retrievers		•			•	
9	How can CODIS be used to identify suspects from a drop of blood?	•	•			•	
10	Evidence for lateral gene transfer in aphids	•					
11	Determining the regulation of the <i>lac</i> operon	•					
12	Inactivation of specific genes using CRISPR-Cas9 gene editing	•					
13	Observing and measuring phenotypic evolution	•					
14	Forensic phylogeny					•	
15	Why was the 1918–1919 influenza pandemic so severe?				•	•	•
16	Reinforcement of reproductive isolation	•					
17	Changes in Earth's physical environment have affected the evolution of life		•	•			
18	Putting bacteria to work					•	
19	Using phylogenies to make predictions				•		
20	Coevolution of plants and their pollinators	•					
21	How dependent are plants on their fungal mutualists?		•				
22	How do biologists estimate how many species are still undiscovered?			•			
23	How can one identify the anatomical parts of a plant if they appear unfamiliar?	•					
24	Testing new analytical methods: Might <i>Tillandsia</i> make useful air pollution monitors?		•			•	
25	Correlation and causation	•					
26	Impact of temperature on the bloom time of plants near Walden Pond in Concord, Massachusetts		•			•	•
27	Modeling Earth's carbon cycle		•	•		•	
28	Using quantitative reasoning to communicate with nonscientists about "burning off" extra food calories		•				•
29	Is global warming affecting animal life or not?	•				•	

Core Competencies

THINK LIKE A SCIENTIST

Chapter	Title	Process of Science	Quantitative Reasoning	Modeling & Simulation	Interdisciplinary	Science & Society	Communicate & Collaborate
30	How does a person's maximal rate of O ₂ consumption vary with elevation in the mountains?		●				
31	Do some moths jam bats' echolocation mechanism?	●					
32	Commercialization of hormones: New choices for people to make	●					●
33	From the shores of ancient Rome to flashing muscle fibers: Progress in a stunning collaboration across generations of scientists, disciplines, animals, and tissues	●			●		●
34	The value of manipulative experiments	●	●		●		
35	Differentiation can be due to inhibition of transcription factors	●					
36	Avoiding incompatibilities in blood type: The immune response to the Rh factor					●	
37	How are animals reacting to global warming?	●					
38	Phylogenetic methods contribute to our understanding of biogeography	●			●		
39	Dispersal corridors can "rescue" fragmented populations from extinction	●	●				
40	Intra- and interspecific competition influence the morphology of coexisting species	●	●				
41	Additional predictions of the MacArthur-Wilson theory can be tested	●	●				
42	Computer models of Earth's climate link global warming to human activities		●	●	●	●	●



Process of Science



Modeling & Simulation



Science & Society



Quantitative Reasoning



Interdisciplinary



Communicate & Collaborate

Mastering the Key Concepts

Each chapter of *Principles of Life* is built around a pedagogical framework meant to ensure a mastery of all of the important biological concepts in the introductory course.

KEY CONCEPTS

Dividing chapters into sections, every Key Concept explores a single essential concept in light of established facts and relevant experimental evidence, providing the conceptual framework for the chapter, exercises, and questions ahead.



NEW! LEARNING OBJECTIVES

Learning Objectives are provided at the start of each Key Concept. The goal of Learning Objectives is to help you focus your attention as you read each section. At the end of each section, we reinforce the Learning Objectives with exercises/questions in Review & Apply. Learning Objectives encourage active learning and focus on mastering concepts and skills.

17.1

Events in Earth's History Can Be Dated

NEW

LEARNING OBJECTIVES

For a complete list of the learning objectives, see page 10 of the book.

- 17.1.1 Construct a geological map indicating the ages of exposed rocks and use the map to search for fossils of a given age.
- 17.1.2 Select appropriate methods for dating fossils and rocks from different geological time periods.
- 17.1.3 Place important events in biological history onto a time line of Earth's history.

NEW! REVIEW & APPLY

This new feature is designed to briefly summarize the previous section, and help you master concepts and competencies through questions. R&A questions are concept-specific, aligning with the Learning Objectives. With the exception of introductory concepts, R&A questions tend to be higher-level Bloom's, and when possible, ask you to engage in an activity-based answer.

REVIEW & APPLY | 17.1

NEW

- R** The layering of sedimentary rock strata enables geologists to determine the relative ages of fossils. Assigning actual ages to these strata requires analysis of radioactive decay, paleomagnetic dating, and fossil comparisons across strata. Geologists divide the history of life into eons, eras, and periods based on assemblages of fossil organisms found in successive layers of rocks.
- A** Imagine you have been assigned the job of producing a geological map of rocks that were formed between 600 and 400 million years ago (mya). You collect a sample from each of ten sites (1–10 on the map below), determine the ratio of ^{206}Pb to ^{238}U for each sample, and use these ratios to estimate the ages of the rock samples, resulting in the table on the following page.



Site	$^{206}\text{Pb}/^{238}\text{U}$ ratio	Estimated age (mya)
1	0.076	474
2	0.077	479
3	0.069	431
4	0.081	505

Mastering the Key Concepts

NEW! VISUAL SUMMARIES

Visual Summaries conclude every chapter, providing a visually compelling checklist, emphasizing major chapter concepts through key figures, bullets, and lower-level Bloom's questions. The Visual Summary ensures you have mastered the major points of the chapter. The content is laid out so as to facilitate referencing back to the original chapter text and figures, and directing you to relevant animations and activities. (See the LaunchPad section for details.)

13
VISUAL SUMMARY
NEW

13.1 Evolution Is Both Factual and the Basis of Broader Theory

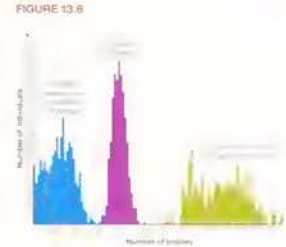
Go to [ACTIVITY 13.1](#)

- **EVOLUTION** is genetic change in populations over time. Evolution can be observed directly in living populations as well as in the fossil record of life.
- **EVOLUTIONARY THEORY** refers to our understanding of the mechanisms of evolutionary change.
- Charles Darwin is best known for his ideas on the common ancestry of divergent species and on **NATURAL SELECTION** (the differential survival and reproduction of individuals based on variation in their traits) as a mechanism of evolution.

13.2 Mutation, Selection, Gene Flow, Genetic Drift, and Nonrandom Mating Result in Evolution


Go to [ACTIVITIES 13.2 and 13.3](#)

FIGURE 13.8



- Mutation is the source of the genetic variation on which mechanisms of evolution act.
- Within **POPULATIONS**, selection acts to increase the frequency of beneficial **ALLELES** and to decrease the frequency of deleterious alleles (**FIGURE 13.6**).
- **GENE FLOW**, **GENETIC DRIFT**, and **NONRANDOM MATING** (as arises from **SEXUAL SELECTION**) can also result in the evolution of populations (**FIGURE 13.8**).

FIGURE 13.8



QUESTIONS


1. Explain the difference between “the fact of evolution” and what scientists mean by “evolutionary theory.”
2. What did Darwin mean by “descent with modification”?
3. How did Darwin suggest that biological evolution could occur?

13.3 Evolution Can Be Measured by Changes in Allele Frequencies

Go to [ACTIVITY 13.4](#)

FIGURE 13.12

Genetic drift: Hardy-Weinberg equilibrium restored



- Allele frequencies measure the amount of genetic variation in a population. Genotype frequencies show how a population's genetic variation is distributed among its members. Together, allele and genotype frequencies describe a population's **GENETIC STRUCTURE**.
- **HARDY-WEINBERG EQUILIBRIUM** predicts genotype frequencies from allele frequencies in the absence of evolution. Deviation from these frequencies indicates that evolutionary mechanisms are at work (**FIGURE 13.12**).

QUESTIONS

1. How many generations of random mating are required to achieve Hardy-Weinberg equilibrium expectations?
2. How do the assumptions of Hardy-Weinberg equilibrium correspond to the five principal processes of evolution?

NEW

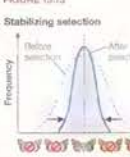
13.4 Selection Can Be Stabilizing, Directional, or Disruptive

Go to [ANIMATION 13.1](#)

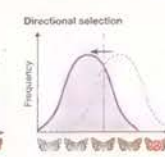
- **STABILIZING SELECTION** acts to reduce variation without changing the value of a trait (**FIGURE 13.13**).
- **DIRECTIONAL SELECTION** acts to shift the mean value of a trait toward extreme (**FIGURE 13.13**).
- **DISRUPTIVE SELECTION** favors both extremes of a trait value, resulting in bimodal character distribution (**FIGURE 13.13**).

FIGURE 13.13

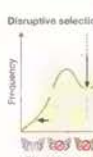
Stabilizing selection



Directional selection

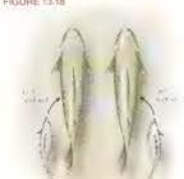


Disruptive selection




13.5 Selection Can Maintain Polymorphisms in Populations

FIGURE 13.18



- A polymorphism may be maintained by **FREQUENCY-DEPENDENT SELECTION** when the fitness of a genotype depends on its frequency in a population (**FIGURE 13.18**).
- A polymorphism may also be maintained by heterozygote advantage when the fitness of the heterozygote exceeds the fitness of either homozygote.
- Genetic variation within species may be maintained by the existence of genetically distinct populations over geographic space. A gradual change in phenotype across a geographic gradient is known as **CLINAL VARIATION** (**FIGURE 13.20**).

FIGURE 13.20



Go to [LaunchPad](#) for the eBook, LearningCurve, animations, activities, flashcards, and additional resources and assignments.

“

VISUAL SUMMARY is fantastic. It can be interpreted by itself and students can learn independently from the text. I like the questions next to the summary as well. I do like all the application questions (TLAS, R&A, and Investigations). Students always want more practice, and more application questions, so these are invaluable.”

Shira D. P. Rabin,
 University of Louisville

Developing Skills and Working with Data

Principles of Life has always been known for emphasizing the role of experimentation, data, and research in our understanding of biology. The Third Edition includes even more tools to help you understand how we know what we know.

INVESTIGATION

FIGURE 18.14 What Is the Highest Temperature Compatible with Life? Can any organism thrive at temperatures above 120°C? This is the temperature used for sterilization, known to destroy all previously described organisms. Kazem Kashefi and Derek Lovley isolated an unidentified prokaryote from water samples taken near a hydrothermal vent and found it survived and even multiplied at 121°C. The organism was dubbed “Strain 121,” and its gene sequencing results indicate that it is a prokaryotic archaeal species.⁹

HYPOTHESIS

Some prokaryotes can survive at temperatures above 120°C.

METHOD

1. Seal samples of unidentified, iron-reducing, thermal vent prokaryotes in tubes with a medium containing Fe³⁺ as an electron acceptor. Control tubes contain Fe³⁺ but no organisms.
2. Hold both tubes in a sterilizer at 121°C for 10 hours. If the iron-reducing organisms are metabolically active, they will reduce the Fe³⁺ to Fe²⁺ (as magnetite, which can be detected with a magnet).

RESULTS

The solids are attracted to the magnet, indicating that the organisms in this solution are alive and engaged in iron-reducing biochemical reactions.



From K. Kashefi, A. D. G. Lovley, 2003, *Science* 301: 924. Courtesy of Kazem Kashefi.

CONCLUSION

Prokaryotic archaea of Strain 121 can survive at temperatures above the previously defined sterilization limit.

ANALYZE THE DATA

After Kashefi and Lovley isolated Strain 121, they examined its growth at various temperatures. The table below shows generation time (time between cell divisions) at nine temperatures.

Temperature (°C)	Generation time (hr)
85	10
90	4
95	3
100	2.5
105	2
110	4
115	6
120	20
130	No growth, but cells not killed

INVESTIGATIONS WITH ANALYZE THE DATA QUESTIONS

Highly acclaimed by adopters, Investigations and Analyze the Data return in the Third Edition. The goal of the Investigations is to help you master both big concepts in biology and *Vision and Change* competencies. This is done by illustrating a real study and having you analyze the resulting real data. Investigations with Analyze the Data questions are higher-level Bloom's, integrating concepts within the chapter or across chapters, and encouraging activity-based answers. In addition, LaunchPad includes online companions to the Analyze the Data exercises. (See the LaunchPad section for details.)

RESEARCH TOOLS

Throughout *Principles of Life*, this feature focuses on techniques and quantitative methods scientists use to investigate biological systems.

RESEARCH TOOLS

FIGURE 13.11 Calculating Allele and Genotype Frequencies Allele and genotype frequencies for a gene locus with two alleles in the population can be calculated using the equations in panel 1. When the equations are applied to two populations (panel 2), we find that the frequencies of alleles *A* and *a* in the two populations are the same, but the alleles are distributed differently between heterozygous and homozygous genotypes.

- 1 In any population, where *N* is the total number of individuals in the population:

$$\text{Frequency of allele } A = p = \frac{2N_{AA} + N_{Aa}}{2N} \quad \text{Frequency of allele } a = q = \frac{2N_{aa} + N_{Aa}}{2N}$$

$$\begin{aligned} \text{Frequency of genotype } AA &= N_{AA}/N \\ \text{Frequency of genotype } Aa &= N_{Aa}/N \\ \text{Frequency of genotype } aa &= N_{aa}/N \end{aligned}$$

- 2 Compute the allele and genotype frequencies for two separate populations of *N* = 200:

Population 1 (mostly homozygotes)	Population 2 (mostly heterozygotes)
$N_{AA} = 90$, $N_{Aa} = 40$, and $N_{aa} = 70$	$N_{AA} = 45$, $N_{Aa} = 130$, and $N_{aa} = 25$

Developing Skills and Working with Data

“ I think this (REVIEW & APPLY) is a great feature. Applying what they’ve just read in a slightly new way will improve understanding and retention....”

Jennifer Butler, Willamette University

MAKING SENSE OF DATA: A STATISTICS PRIMER

This primer (an appendix in the text and also in LaunchPad) lays the proper groundwork for understanding statistics and data, providing helpful support for all of the quantitative exercises in the new edition.

How Does Statistics Help Us Understand the Natural World?

Statistics is essential to scientific discovery. Most biological studies involve five basic steps, each of which requires statistics:

- **Step 1: Choose an Experimental Design**
Clearly define the scientific question and the methods necessary to tackle the question.
- **Step 2: Collect Data**
Gather information about the natural world through observations and experiments.
- **Step 3: Organize and Visualize the Data**
Use tables, graphs, and other useful representations to gain intuition about the data.

REVIEW & APPLY | 16.3

NEW

- R** Allopatric speciation results from the separation of populations by geographic barriers; it is the dominant mode of speciation among most groups of organisms. Sympatric speciation may result from disruptive selection that results in ecological isolation, but polyploidy is the most common cause of sympatric speciation among plants.
- A**
1. Explain how speciation via polyploidy can happen in only two generations.
 2. If allopatric speciation is the most prevalent mode of speciation, what do you predict about the geographic distributions of many closely related species? Does your answer differ for species that are sedentary versus highly mobile?
 3. The species of Darwin’s finches shown in the phylogeny in Figure 16.8 have all evolved on islands of the Galápagos archipelago within the past 3 million years. Molecular clock analysis (see Key Concept 14.3) has been used to determine the dates of the various speciation events in that phylogeny. Geological techniques for dating rock samples (see Key Concept 17.1) have been used to determine the ages of the various Galápagos islands. The table shows the number of species of Darwin’s finches and the number of islands that have existed in the archipelago at several times during the past 4 million years (data from P. R. Grant. 2001. *Oikos* 92: 385–403).

Time (millions of years ago)	Number of islands	Number of finch species
0.25	18	14
0.50	18	9
0.75	9	7
1.00	6	5
2.00	4	3
3.00	4	1
4.00	3	0

- a. Plot the number of species of Darwin’s finches and the number of islands in the Galápagos archipelago (dependent variables) against time (independent variable).
 - b. Are the data consistent with the hypothesis that isolation of populations on newly formed islands is related to speciation in this group of birds? Why or why not?
4. If no more islands form in the Galápagos archipelago, do you think that speciation by geographic isolation will continue to occur among Darwin’s finches? Why or why not? What additional data could you collect to test your hypothesis (without waiting to see if speciation occurs)?

Active Learning

Active learning continues to be central to the mission of *Principles of Life*. New features both in the text and online present you with an even more engaging experience.


NEW! CHAPTER OPENER WITH QUESTION

A short introduction with an attention-grabbing photo and compelling question gives you something to ponder while reading and studying the chapter. The chapter ends with a return to the question and some discussion of the answer.

The History of Life on Earth 17

NEW

Goliath beetles (*Goliathus* spp.) are among the largest species of flying insects alive today. But in earlier periods of Earth's history, there were much larger flying insect predators—the size of modern birds of prey. Such giant insects cannot live and fly in Earth's present environment.



What differences in Earth's past environment allowed flying insects to attain much larger sizes than they do today?

You will find the answer to this question on page 409.

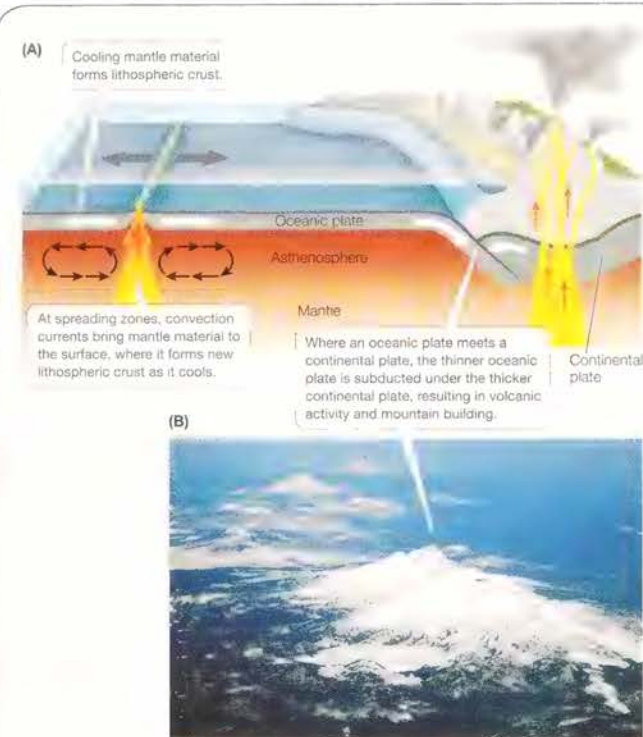
LINKS

Links point you to additional discussion of a concept or key term elsewhere in the book, providing an opportunity for integration across chapters.

LINK **Key Concept 14.3** describes how biologists reconstruct the gene sequences of extinct organisms.

NEW! IN-FIGURE QUESTIONS

Incorporated into figures, these questions are designed to engage you and help you think about the implications of the figure/diagram. In-figure questions tend to be lower-level Bloom's, and are often amenable to in-class discussion.



(A) Cooling mantle material forms lithospheric crust.

Oceanic plate

Asthenosphere

Mantle

Continental plate

At spreading zones, convection currents bring mantle material to the surface, where it forms new lithospheric crust as it cools.

Where an oceanic plate meets a continental plate, the thinner oceanic plate is subducted under the thicker continental plate, resulting in volcanic activity and mountain building.

(B)

FIGURE 17.2 Plate Tectonics and Continental Drift (A) The heat of Earth's core generates convection currents in the viscous mantle material underlying the oceanic and continental plates. Those currents push the continental plates, along with the land masses they carry, together or apart. Where plates collide, one may slide under the other, creating mountain ranges and often volcanoes. (B) The Cascade Range of the Pacific Northwest of North America is an example of a mountain chain produced by subduction of an oceanic plate under a continental plate.

Why are both shores of the Pacific Ocean ringed with volcanic mountain ranges?

Media Clip 17.2 Lava Flows and Magma Explosions
PoL3e.com/mc17.2

NEW

Why are both shores of the Pacific Ocean ringed with volcanic mountain ranges?

Media Clip 17.2 Lava Flows and Magma Explosions
PoL3e.com/mc17.2

Active Learning

Encouraging you to be more involved while reading the textbook is just the beginning of the Active Learning approach in *Principles of Life*. For instructors who have been teaching actively for years, or those who are just beginning to use these techniques, we've created an Active Learning Guide and an accompanying set of Active Learning Modules to engage you before, during, and after class.

EXPANDED! ACTIVE LEARNING MODULES

Chemiosmotic Mechanism

Examining Mitochondrial Poisons: Cyanide

In your groups, predict what effect HCN would have on the inputs and outputs of these reactions. What will build up, and what will be depleted?

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Examining Mitochondrial Poisons:

In your groups, predict what effect HCN would have on the inputs and outputs of these reactions. What will build up, and what will be depleted?

1. Rotenone - inhibits complex I
2. DNP - shuttles protons across the mitochondrial membrane
3. Oligomycin - blocks the proton channel of ATP synthase

Active Learning Module In-Class Exercise Slides

The expanded Active Learning Modules provide everything instructors need to successfully implement an active approach to teaching key topics. Each module's many resources include:

- Pre-class video specifically created for the module
- Pre-quiz and post-quiz
- Handout for in-class work
- Detailed in-class exercise
- Detailed instructor's guide

These modules are easy to implement and are a great way to add more active learning to the classroom.

Transpiration-Cohesion-Tension Theory

Water potential ↑
Lower
Higher

Movement of water depends on:

- 1) the chemical properties of water
- 2) a gradient in water potential
- 3) avoiding cavitation

The last in this list is cavitation, which is the primary threat to the movement of water within xylem vessels.

Active Learning Module In-Class Video

NEW! ACTIVE LEARNING GUIDE

The Active Learning Guide provides extensive resources and support for implementing active learning techniques in any classroom, large or small. This all-new guide provides instructors with a thorough introduction to the concepts, techniques, and benefits of active learning. Chapter-by-chapter guidance provides strategies for how to best utilize learning resources in *Principles of Life* to teach in a more active format.

Part 1: Introduction to Active Learning

Chapter 1: What Is Active Learning?

Chapter 2: Designing Your Course for Active Learning

Chapter 3: Using Active Learning in the Classroom

Chapter 4: How to Implement *Principles of Life* Resources

Part 2: Active Learning Resources and Suggestions by Chapter

Each chapter in Part 2 of the Active Learning Guide corresponds to a textbook chapter and includes the following:

- An overview of the textbook chapter
- References to all of the student media resources, listed by Key Concept
- References to and descriptions of each Active Learning Module
- Detailed suggestions for active learning activities and exercises for each Key Concept, including "draw," "video," and "compare" exercises, think-pair-share activities, spider maps, minute papers, clicker questions, and more
- Suggestions for incorporating the in-text Links and Analyze the Data features into in-class activities

Part 3: Appendices

- Appendix A: An Overview of Bloom's Taxonomy
- Appendix B: A Guide to Using the *Principles of Life*, Third Edition Learning Objectives
- Appendix C: Learning Objectives for *Principles of Life*, Third Edition

LaunchPad

The complete experience of *Principles of Life* is delivered through LaunchPad, our online learning platform.

Built to address the most challenging classroom issues instructors face, LaunchPad gives you everything you need to prepare for class and exams. At the same time, LaunchPad gives instructors the tools *they* need to quickly set up a course, shape the content to their syllabus, craft presentations and lectures, assign and assess homework, and guide the progress of individual students and the class as a whole.

Membrane Transport Simulation

Challenge: Using active transport, make the extracellular solution hypertonic (take molecules).

Extracellular Solution: Isotonic (95 extracellular, 98 intracellular)

Reset with different number of total molecules (split evenly among red and blue):

Temperature: [Slider]

Molecule size (Permeability): [Slider]

+/− Molecules: [Slider]

Uniproters (active transport): [Buttons]

Extracellular	Red (31)	Blue (95)
Intracellular	Red (19)	Blue (98)
Intramembrane	Red (0)	Blue (7)

Textbook Reference: Key Concept 4.2 Passive and Active Transport Are Used by Small Molecules to Cross Membranes

Activity 4.3: Membrane Transport Simulation

LaunchPad is organized into units that mirror the textbook's chapters. Each unit includes the e-Book chapter, organized by Key Concept, with integrated media resources, chapter-specific assessment, and other resources.

All of LaunchPad's resources directly support *Principles of Life*, Third Edition. Assessment, media resources, exercises, and other components are aligned clearly to the textbook's Key Concepts.

Substantial new active learning resources—such as the activity and animation shown here—support the use of the book in an active learning context.

ANIMATIONS

Bacteriophage outgroup
Bacteria in broth + **mutagen**

Bacteriophage ingroup
Bacteria in broth + **mutagen**

A T7 bacteriophage injects its DNA into a host cell of *E. coli*, resulting in the production of numerous progeny viruses and the lysis of the cell.

Textbook Reference: Key Concept 14.2 Phylogeny Can Be Reconstructed from Traits of Organisms

Animation 14.1: Using Phylogenetic Analysis to Reconstruct Evolutionary History

LearningCurve

Analyze the Data 13.19: A Heterozygote Mating Advantage

Each in-text Analyze the Data exercise is accompanied by an online companion exercise in LaunchPad. The online companion exercise gives you additional practice with the same skills addressed by the in-text exercise, and can be assigned by your instructor.

Species	Number of Males	Number of Females	Number of Offspring	Relative Fitness
<i>C. philodice</i>	38/84	45.2	35/48	72.9
<i>C. eurytheme</i>	42/90	46.7	49/64	76.6

*"Visible males" are all males captured flying with females (hence with the potential to mate)

Questions

- 1 pt. Researcher wants to see if there is a heterozygote advantage in the other with the same color. What would be the best way to test this?
 - One that is heritable but in which the genes that affect the trait are not yet known
 - One in which the offspring resemble parents
 - One that is highly subject to environmental modification
 - One that is visible to the naked eye
- 1 pt. Researcher wants to see if there is a heterozygote advantage in the other with the same color. What would be the best way to test this?
 - One that is heritable but in which the genes that affect the trait are not yet known
 - One in which the offspring resemble parents
 - One that is highly subject to environmental modification
 - One that is visible to the naked eye

Online companion to in-text Analyze the Data exercise

Each in-text Analyze the Data exercise is accompanied by an online companion exercise in LaunchPad. The online companion exercise gives you additional practice with the same skills addressed by the in-text exercise, and can be assigned by your instructor.

“The LAUNCHPAD program is amazing, I wish all my classes used similar programs. I really liked how each chapter is broken into sections, and those sections broken into smaller subsections. This not only made reading the chapters extremely easy, but also helped me stay organized with note taking. The LearningCurve exercises were my favorite part of LaunchPad. They really helped me memorize information, and if I happened to forget something it was easy to go back and re-read the section of the book it was in.”

Student User

LearningCurve adaptive quizzing gives you individualized question sets and feedback based on your responses. All questions link back to the e-Book to encourage you to read the book in preparation for class-time and exams.

LearningCurve organizes questions by Key Concept, and instructors can easily hide questions on concepts they are not covering. This means that each quiz can focus on the exact content being taught.

Chapter 14: Reconstructing and Using Phylogenies

Target score progress: You have **226** points / Target **750**

Your personalized study plan:

- Key Concept 14.1 All of Life Is Connected through Its Evolutionary History: 48%
- Key Concept 14.2 Phylogeny Can Be Reconstructed from Traits of Organisms: 33%
- Key Concept 14.3 Phylogeny Makes Biology Comparative and Predictive: 100%
- Key Concept 14.4 Phylogeny Is the Basis of Biological Classification: 78%

Study plan suggestions:

- eBook: 14.2 Phylogeny Can Be Reconstructed from Traits of Organisms
- Activity 14.1: Constructing a Phylogenetic Tree
- Animation 14.1: Using Phylogenetic Analysis to Reconstruct Evolutionary History

Target Score Progress: [Progress bar] [Back to study plan](#)

Hint

What property makes a trait much less likely to be useful in determining phylogenetic relationships?

Which morphological trait would a biologist most likely exclude from use in phylogenetic analysis?

- One whose genetic basis is known down to specific nucleotides
- One that is heritable but in which the genes that affect the trait are not yet known
- One in which the offspring resemble parents
- One that is highly subject to environmental modification
- One that is visible to the naked eye

Need help on this question?

[Read the ebook page on this topic](#) [Get a Hint](#) [Show answer](#)

Learning Curve instructor and student views

Assessment

Principles of Life's assessment resources give instructors a range of tools for assessing your progress before class, after class, and on exams. Along with updating and revising all question banks and adding new questions at higher cognitive levels, we have fully aligned all in-book and online content to the new Third Edition.

Third-Edition assessment questions and resources are aligned to the new Learning Objectives featured in each Key Concept. This provides instructors with a concrete way of assessing you on your mastery of the most important material in each chapter.

SEARCHABLE QUESTION BANK

LaunchPad's enhanced question bank functionality makes it easy to search for and select questions from any of the *Principles of Life* question banks (Test Bank, LearningCurve, Summative Quizzes). With the new filtering functionality, instructors can get the precise mix of questions they want by filtering for:

- Learning Objective
- Key Concept/Textbook Section
- Bloom's Taxonomy Level
- Difficulty (for LearningCurve questions)
- Source

SUMMATIVE QUIZZES

In LaunchPad, each chapter includes a Summative Quiz composed of 20 questions spanning the chapter's Key Concepts. Quizzes are pre-built and ready to assign. At the same time, they are completely customizable; instructors can add, revise, or remove questions to match their course content.

LEARNINGCURVE

For each chapter, LearningCurve offers an extensive set of questions that are distinct from those in the Test Bank and Summative Quizzes. Questions are organized by Key Concepts and ranked by difficulty. Thus, you can master the material at a manageable pace, facing more difficult questions after answering easy and moderate questions correctly.

TEST BANK

The *Principles of Life* Test Bank has been significantly revised for the Third Edition. Questions have been updated to match the revised textbook chapters and aligned to the new Learning Objectives. In addition, the number of questions at higher cognitive (Bloom's) levels has been increased. All questions are available in LaunchPad and are easily searchable by chapter, Key Concept, Learning Objective, and Bloom's Level using LaunchPad's new question bank tools.

FEATURE	LAUNCHPAD ASSESSMENT RESOURCES
Active Learning Modules	The expanded set of Active Learning Modules includes pre- and post-quizzes in LaunchPad, plus additional assessment questions.
Activities & Simulations	All activities, including simulations, are assignable in LaunchPad and report to the LaunchPad gradebook upon completion.
Analyze the Data	For each in-text Analyze the Data exercise, a companion exercise is available in LaunchPad.
Animations	Pre-built quizzes accompany each Animation in LaunchPad.
Key Concepts	<ul style="list-style-type: none"> • All quiz and test questions are tagged by Key Concept and searchable in LaunchPad. • LearningCurve study plans and instructor reports are organized around the Key Concepts.
Learning Objectives	Learning Curve, Summative Quiz, and test questions align with the new Learning Objectives and are searchable in LaunchPad.
Summative Quizzes	Each chapter includes a pre-built Summative Quiz in LaunchPad.
Test Bank	An extensive Test Bank is provided for each chapter in a variety of formats: LaunchPad question banks, Word documents, and Respondus format.

Preface

We are standing at an important crossroad in biology education, with an opportunity for lasting change in the way we teach introductory biology. Numerous reports and studies published by education agencies and national study groups since the turn of the millennium have advocated a shift away from an emphasis on facts and memorization. Two major reports in particular have encouraged this change: *Vision and Change in Undergraduate Biology Education: A Call to Action*, published by the American Association for the Advancement of Science (supported by the National Science Foundation) at the time of the First Edition of *Principles of Life*; and *BIO2010: Transforming Undergraduate Education for Future Research Biologists*, sponsored by the National Institutes of Health and the Howard Hughes Medical Institute. These reports recommend focusing on core concepts and competencies, teaching students through active learning rather than memorization, and improving the integration of statistical and computational approaches. From the First Edition of *Principles of Life*, we have used our experience as authors and educators to implement these recommendations for a new approach to teaching introductory biology.

In this, the Third Edition of *Principles of Life*, we continue to stress the five core themes identified in *Vision and Change*:

- Evolution
- The relationship between structure and function
- Information flow, exchange, and storage
- Pathways and transformations of energy and matter
- Biological systems

As we develop these themes, we keep a steady focus on the needs of beginning students at the university level. In preparing each chapter, our central question has been, “What does a beginning student need to know?” We have then met the needs of the beginning student with a concept-centered approach that introduces facts and terms as they are needed to develop concepts, avoiding the inclusion of terms and facts for their own sake. For students who go on in biological science, *Principles of Life*, Third Edition, provides the conceptual foundation they will need to succeed in upper-level courses. For the many students who complete their study of biology at the introductory level, *Principles of Life* recognizes that—long after a year of study—people remember concepts, not isolated facts.

In writing *Principles of Life*, Third Edition, we have doubled our emphasis on active learning. Each section within each chapter starts with carefully worded *Learning Objectives* so that students can clearly see the goals they will achieve in their studies. Chapter openers have been completely revised with active learning in mind. Each chapter begins with a brief statement focused on major themes, accompanied by a dramatic photograph and interpretive questions for students to consider. These opening questions are designed so that students will be able to offer tentative answers as they start a chapter but will

be able to offer far more thorough answers as they finish. At the end of each chapter, we reprise the opening photograph with an answer of our own.

Also, to promote active learning, each section in each chapter ends with a *Review & Apply*, in which we present a concise summary and a set of study questions. Many of these questions encourage students to go beyond memorization and engage more thoroughly in the process of science. As with all study questions in the book, we provide answers in LaunchPad, our online companion site.

Each chapter includes an *Investigation*, in which we unpack the logic of real, important research using actual data sets from the scientific literature. The *Investigation* often includes an *Analyze the Data* feature that presents questions that guide students through the interpretation of results, often tying in with our *Making Sense of Data: A Statistics Primer* (Appendix B). As students read a chapter, they will also encounter occasional questions tied to illustrations: questions that highlight what can be learned from the illustrations and associated text.

Each chapter ends with a dramatic new feature: a *Visual Summary* that helps students review the content of the chapter. To help students recall what they have learned, the *Visual Summary* includes both illustrations (especially helpful for visual learners) and bulleted points. The *Visual Summary* also includes additional study questions about each section in the chapter. Again, answers to all questions are provided online.

Another new feature found in each chapter—*Think Like a Scientist*—provides additional opportunities for active learning focused on the core competencies recommended by *Vision and Change*. *Vision and Change* argues that students need to cultivate six core competencies to become biologically literate. Students should be able to

- apply the process of science;
- use quantitative reasoning;
- use modeling and simulation;
- tap into the interdisciplinary nature of science;
- communicate and collaborate with other disciplines;
- understand the relationship between science and society.

The *Think Like a Scientist* feature in each chapter emphasizes one or more of these core competencies (using icons to highlight the particular competencies). Topics such as manipulative experiments, proper choice of controls, meta-analysis, and communicating science to the public are presented in ways that (true to the name of the feature) will help each student learn more about the ways that scientists think. Questions (with online answers) are often provided to stimulate student engagement.

The art program in *Principles of Life*, Third Edition, plays an essential role in our concept-centered approach. It has been entirely revised using new color palettes that are more attractive and ensure all readers can learn from the illustrations

PREFACE

regardless of their color vision. New conceptual diagrams have been added in many places, and text–art coordination has been emphasized. To be certain students know the organisms being discussed, the pages of the book are profusely illustrated with photographs and drawings of the animals, plants, and other organisms cited. When diagrams or data sets from the scientific literature are presented, readers will now be able to find those diagrams or data sets in the literature with our new referencing system. Unlike in previous editions, all figures now have figure numbers, enhancing the ability of both students and instructors to find and use figures.

To help students deepen their understanding, we provide *Links* that allow students to see interconnections among such topics as molecular or cell biology, evolution, biological diversity, physiology, and ecology. With this edition, the *Links* are not merely cross-references but include brief statements of pertinence, helping readers see why they might want to follow a *Link*. We have also added more online *Animations* and *Activities*, which include opportunities for students to use modeling and simulation modules to further reinforce their understanding of concepts.

The Principles of Life Story

Prior to our launch of the First Edition of *Principles of Life*, introductory biology textbooks for science majors presented encyclopedic summaries of biological knowledge. We believe that students who spend their time diligently memorizing myriad details and vast terminology actually retain fewer of the concepts that are the foundation for further study in advanced courses. In *Principles of Life*, we take the opposite approach: we promote understanding over memorization. Details are important, but no modern biology textbook can begin to cover all the information biologists have learned to date, and students today have many other ways to access the details as they need them.

To help us create this new breed of biology textbook, in 2009 our publishers—Sinauer Associates (now an imprint of Oxford University Press) and W. H. Freeman (now Macmillan Learning)—brought together an Advisory Board of twenty leading biology educators and instructors in introductory biology from throughout North America. During an intensive meeting of the authors and the Board, dynamic discussions led to the solidification of the core concepts we believe are essential for teaching introductory biology. The book took shape, and the Advisory Board members then reviewed the emerging chapters and provided considerable feedback at every stage of the book's development.

For the Third Edition, all chapters have undergone extensive between-edition review by experts in each respective discipline, and the chapters have been revised both to respond to reviewer input and to incorporate new pedagogical features. Active learning has always been a priority in *Principles of Life*. With the Third Edition, the emphasis on active learning has been dramatically enhanced—to the point that active-learning features permeate the book. We have expanded opportunities for students to apply what they have learned by using real data and examples—and have better integrated and explained the concepts of statistical analysis of data. Our coverage and application of biological

systems are expanded. With the new *Think Like a Scientist* feature, we have developed opportunities for students to practice the core competencies that have become critical for modern biology. With our *Visual Summaries*, we believe we provide a review feature so enticing that students will be drawn to it and thus experience important reinforcement.

Features of the Third Edition

Each chapter is organized into a series of *Key Concepts*, each with its own *Learning Objectives*. Our focus in each *Key Concept* is to identify and explain the concepts that beginning university students need to know. *Principles of Life* is focused on these concepts; it is not meant to be encyclopedic. At the end of each *Key Concept*, a *Review & Apply* concisely recaps the main points and presents questions related to the *Learning Objectives* for students to ponder. At the end of the chapter, the *Visual Summary* follows up with a visual and narrative review of major concepts throughout the chapter—and provides further questions related to the *Learning Objectives*. Throughout, questions are deliberately designed to span the incremental levels of Bloom's Taxonomy of Cognitive Domains: factual knowledge, comprehension, application, analysis, synthesis, and evaluation. As already stressed, we provide answers to all questions in LaunchPad, *Principles of Life's* online platform.

Each chapter includes additional features in several places, including an *Investigation*, a *Think Like a Scientist* feature, and often an *Analyze the Data* feature. Each of these features reinforces a concept that is central to the chapter and develops a core competency. The features hone in on specific questions, points of view, and types of data of importance to the chapter. Because science students need to understand basic methods for data presentation and analysis, many of the features ask students about interpretation of results, especially statistical significance. To help students understand issues in data presentation and interpretation, we provide a short introduction to the reasoning behind biological statistics in our Appendix B: *Making Sense of Data: A Statistics Primer*. Although this appendix is not meant to replace a more formal introduction to statistics, we believe that data interpretation and statistical thinking are essential skills that should be integral to all introductory science courses.

The *Investigations* help students learn the process of science by being organized into sections on Hypothesis, Method, Results, and Conclusion. Most include a section (*Analyze the Data*) in which we present a subset of original data from the published experiment. Students are asked to analyze these data and to make connections between observations, analyses, hypotheses, and conclusions.

Another important element for achieving student success is reinforcement and application of concepts through three types of online features in LaunchPad: *Animations*, *Activities*, and *Media Clips*. For many concepts, in the *Animations* and *Activities* students can conduct their own simulations, explore a concept in greater depth, and understand concepts through active discovery. Using the *Media Clips*, they can also watch videos that help explain concepts or introduce them to the wonders of biological diversity.

Students need to learn about some of the major research tools that are used in biology, including major laboratory, computational, and field methods. At key places, we provide *Research Tools* figures that explain these tools and explain the contexts in which they are used by biologists. With the Third Edition, we have also added a new appendix on *Working with DNA* (Appendix D) so that students have an easy place to review and understand the major methods of molecular genetics.

Our art program for *Principles of Life* continues to build on our success in *Life: The Science of Biology*. We pioneered the use of balloon captions to help students understand and interpret the biological processes illustrated in figures without repeatedly going back and forth between a figure, its legend, and the text. These guides play an invaluable role in text–art coordination, helping students connect critical points of figures to the concepts that are developed in the text.

Special Contributions

Many people contributed to the creation of the Third Edition of *Principles of Life* (see below). However, three individuals deserve special mention and thanks for their contributions. Susan D. Hill did a masterful job in writing Chapter 35 on Animal Development. Nickolas Waser worked extensively with Mary Price on the Ecology section (Part 7) and was otherwise intimately involved in discussions of the book’s planning and execution. David Sadava reprised his Chapter 36 on Immunology and provided expert editorial support on the Cells and Genetics sections (Parts 1 and 2) in the closing months of the project.

Many People to Thank

Our publisher, Andy Sinauer, embraced the need for change in introductory biology textbooks and has helped make our vision a reality. Also at Sinauer Associates, Dean Scudder played a key leadership role in every stage of the book’s development. We extend special thanks to both of them. Bill Purves, Gordon Orians, and Craig Heller, our coauthors on earlier editions of *Life: The Science of Biology* and/or *Principles of Life*, were instrumental in articulating the concepts developed in all editions of *Principles of Life*, and many aspects of this book can be traced back to their critical contributions.

In addition to the many biologists listed on the next page who provided formal reviews, each of us benefitted enormously from personal contacts with colleagues who helped us resolve dilemmas and made critical suggestions for new material. Colleagues deserving particular thanks are Walter Arnold, University of Veterinary Medicine (Vienna); Tobias Baskin, University of Massachusetts, Amherst; John Dacey, Woods Hole Oceanographic Institution; Larry Gilbert, University of Texas, Austin; Harry Greene, Cornell University; Hugo Hofhuis, Wageningen University Research (the Netherlands); Matthew Kayser, University of Pennsylvania; Edward McCabe, University of Colorado and the March of Dimes Foundation; Will Petry, University of California, Irvine; Frank Price, Utica College; Thomas Ruf, University of Veterinary Medicine (Vienna); David Sleboda, Brown University; Viola Willemsen, Wageningen University Research (the Netherlands); and Andrew Zanella, The

Claremont Colleges. Richard Shingles, Johns Hopkins University, worked with each of us to develop a coherent and effective set of Learning Objectives for each chapter and Key Concept. In this way he helped provide a pedagogical framework for the book, including all of the assessment material.

For this edition, Sinauer Associates assembled a talented team of editors. Danna Niedzwiecki Lockwood coordinated the editorial team and organized the multitude of project pieces, along with being the primary editor for Parts 1–4 and 7. Laura Green was the primary editor for Parts 5 and 6. Mara Silver rounded off the editorial team, assisting with the many pieces of the production process. Carol Pritchard-Martinez, our developmental editor, provided important guidance for new authors on the team, and ensured consistency in style and level in text and features throughout the text. Liz Pierson applied her outstanding copyediting skills to our manuscript. Dragonfly Studios worked with each of us to revise and create effective and beautiful line art. Mark Siddall rose to the challenge of finding new, even better photographs, while Michele Beckta managed the permissions process and was ever vigilant in prompting us to track down data sources. Designer Joanne Delphia brought a fresh look to the book, and Donna DiCarlo did a fine job of assembling all of the book’s elements into clear and attractive pages. Chris Small and Joan Gemme coordinated production and imposed their exacting standards on keeping the myriad components consistent. Johannah Walkowicz organized and commissioned the many expert academic reviews. Suzanne Carter coordinated the team, including Carrie Mailler and Peter Lacey, that created the vast array of online media and supplements with help from Tom Friedmann and Jason Dirks in building LaunchPad. Kathaleen Emerson monitored the editorial process from behind the scenes. Rachel Meyers watched over the publication process and was Sinauer Associates’ liaison with Macmillan Learning. At Oxford University Press, we appreciate the ongoing support of John Challice and Petra Recter. At Macmillan, we continue to benefit from the long-term editorial support of Sandy Lindelof, and the marketing expertise of Will Moore, in collaboration with the regional specialists and the regional sales managers. They coordinated all the stages of informing Macmillan’s skilled sales force of our book’s story. We also thank the Macmillan media group for their expertise in producing LaunchPad.

Media and Supplements

The Third Edition of *Principles of Life* features an expanded collection of online resources to support and reinforce the material covered in the textbook. All the Activities, Animations, and Media Clips referenced throughout the book include direct Web addresses, allowing students to link instantly to these resources from any device—computer, smartphone, or tablet—while reading the book.

The *LaunchPad* online platform integrates all the student resources, instructor resources, the complete e-Book, and all assessment tools within a streamlined interface that groups essential content into easily assignable learning units. LaunchPad features a range of assessment tools, including the *LearningCurve* adaptive quizzing engine and pre-built summative quizzes for

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each chapter. To support course preparation, classroom sessions, and assessment programs, there is a wide range of instructor resources available, including multiple versions of all textbook figures, a wealth of PowerPoint presentations, multiple banks of assessment questions, and a large collection of videos. New for this edition is the *Active Learning Guide & Instructor's Manual*, providing extensive resources and support for integrating active learning into the classroom.

For a complete list of all the media and supplements available for *Principles of Life*, please refer to "Media and

Supplements to accompany *Principles of Life*, Third Edition" following this Preface.

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