Principles of Life

THIRD EDITION

DIGITAL UPDATE

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To Our Readers

Welcome to *Principles of Life*. This book is a *concept-centered* introduction to biology. When we ourselves were students, we realized that—six months after a course ended—the concepts were what we remembered. By now, educational research has confirmed that in undergraduate courses, student needs are served best by an emphasis on concepts. With its concept-centered approach, this book is written for you.

With all the rapid advances in information-sharing on the internet, simple facts are easier than ever to look up. This easy accessibility changes our relationship to facts. In particular, it places an ever-increasing premium on our ability to evaluate facts and integrate them into coherent knowledge. This reality helps explain why central organizing frameworks—concepts—are so important.

Some of you intend to go on into science or medicine. For you, *Principles of Life* recognizes that a solid foundation in concepts will be important throughout your career, helping you to assimilate and use ever-enlarging spheres of factual knowledge.

Some of you expect to move on into other interests after completing your introductory courses in science. For you, long-term knowledge will be your pay-off for your study of biology. *Principles of Life* recognizes that you will be most likely to recall concepts, not isolated facts, as years go by.

Believe it or not, scientists and educators occasionally gather together to debate how university and college courses can best serve your needs. A decade ago, a group of about 500 helped formulate a watershed report—*Vision and Change in Undergraduate Biology Education: A Call to Action*.[1]

Two questions—both of great importance to you—are stressed in *Vision and Change* (*V & C*). First, what are the core concepts that students of the twenty-first century need to understand? Second, what competencies—personal abilities—do you need to develop to succeed? *Principles of Life* is focused on helping you master both the core concepts and the competencies.

Principles of Life, as part of its conceptual approach, places central importance on the five **core concepts** pinpointed by V & C:

Principles of Life highlights the six V & C **competencies** in every chapter, helping you develop your ability to:

• evolution	• apply the process of science
• the relationship between structure and function	• use quantitative reasoning
• information flow, exchange, and storage	• use modeling and simulation
• pathways and transformations of energy and matter	• tap into the interdisciplinary nature of science
• systems biology	• communicate and collaborate with other disciplines
	• understand the relationship between science and society

[1]*Vision and Change* is published by the American Association for the Advancement of Science. To read the report, go to https://visionandchange.org/ and upload the 2011 report.

About the Authors

from left: Mary Price, David Hall, Marta Laskowski, David Hillis, Richard Hill

Mark Kirkpatrick

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 taught a variety of classes at Wake Forest University, the University of Texas, and the University of Georgia during his academic career. He especially enjoyed teaching introductory biology and genetics to undergraduates and received several teaching awards for his efforts in the classroom. Ever since high school, he has been captivated by the living world but was initially overwhelmed by the enormous diversity of life. However, he soon realized that there are fundamental principles that unite all organisms, which greatly facilitates the study of biology. Helping students learn these principles was the foundation of his biological teaching.

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 Digital Update

*** = New Chapter**

Principles of Life—Tour of the Third Edition Digital Update

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* 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 Third Edition Digital Update includes 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* 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

Modeling & Simulation

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

A FOCUS ON SKILLS AND CORE COMPETENCIES

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 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

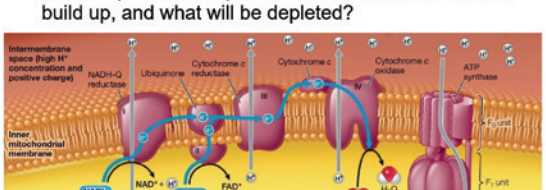
A FOCUS ON DATA

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 Digital Update Content Updates

The Third Edition Digital Update 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.

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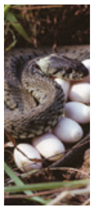
CHAPTER 1

- New Section describing how science informs society using COVID-19 as an example

PART 1: CELLS

- Update to Review & Apply 2.1 to clarify terminology
- Updates to Figures throughout to improve illustrations



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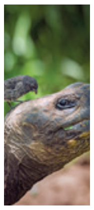
PART 2: GENETICS

- Updates to Figures throughout to improve illustrations
- Update to Link to acknowledge in Chapter 13 students will learn that evolution would be impossible without mutation
- Revised content related to silent mutations
- Revisions to "The information for protein synthesis lies in the genetic code" subsection related to DNA mutations that are synonymous and how tRNA interacts with mRNA; throughout section silent is revised to synonymous
- Revisions to "Stability of mRNA can be regulated" subsection to discuss miRNAs and siRNAs
- Revised Table 12.2 title to: Initial Estimates of Protein-Coding Genes in a Strain of Three Species of Bacteria from Genome Sequencing; updated gene numbers in table
- Revisions to "Metagenomics reveals the diversity of viruses and prokaryotic organisms" subsection to include example about sequencing RNA from nasal samples of COVID-19 patients
- Updates to Table 12.3 to update haploid gene sizes and number of protein-coding genes
- Updated numbers in "The human genome sequence held some surprises" subsection



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PART 3: EVOLUTION

- Revision to introduction to acknowledge COVID-19
- NEW CHAPTER: opening art of phylogenetic trees that depict and track COVID-19 evolution
- New answer to chapter opening question about how phylogenetic methods are used to understand the origin, evolution, and spread of new diseases, like COVID-19
- Revisions in "Molecular evolution is used to study and combat diseases" subsection to acknowledge COVID-19

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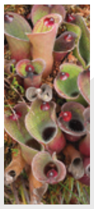
PART 4: DIVERSITY

- Revisions to subsection "The great majority of prokaryotic species have never been studied" to update numbers of described bacteria and species of prokaryotic archae
- Revisions to include COVID-19 as an example of human diseases caused by positive-sense single-strand RNA viruses; update to Figure 18.23 to include description of coronaviruses
- Updates to Table 22.1 to update the approximate number of living species for rotifers and relatives and vertebrates
- Revisions to update numbers referenced to known species of amphibians, anurans, reptiles, living mammals, morphologically diverse eutherians; updates to Table 22.3 to update number of described species of marsupials and eutherians



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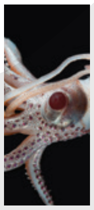
PART 5: PLANT FORM AND FUNCTION

- Updates to Figures throughout to improve illustrations
- Revisions to subsection "Cells that undergo asymmetrical cell division can produce daughter cells with an identity different from that of their parents" to clarify explanation of BASL
- Revisions to "Separation of Male and Female Gametophytes" subsection to clarify how some plant species form two separate types of flowers
- Updates to "Think Like a Scientist: Modeling Earth's carbon cycle" to update data for mean concentration of CO_2 at Mauna Loa for the indicated month
- Review & Apply 27.1 updated by reordering questions and adding new questions #3 & #4, new graph supports question #3



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PART 6: ANIMAL FORM AND FUNCTION

- Updates to Figures throughout to improve illustrations
- Updates to clarify explanation in chapter opening introduction
- Revisions to "Adaptive immunity has four key features" subsection to clarify explanation of herd immunity
- Revision to Answer to chapter opening question "Do people who refuse vaccination for themselves put others at risk" to address COVID-19 vaccinations
- Added online chapter **Water and Salt Balance**

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PART 7: ECOLOGY

- Added Media Clip to subsection "Climate is not the only factor that molds terrestrial biomes" and Figure 38.12 entitled Grasslands and Fire
- Revisions to "Life histories are diverse" subsection to update life expectancy in light of COVID-19
- Revisions to "Knowledge of metapopulation dynamics helps us conserve species and control epidemics" to acknowledge epidemics; added Activity 39.6 COVID-19 Simulation
- Revisions to placement of media Activity 40.5 to appear with Figure 40.10; renamed Evolutionary Arms Race Simulation
- Updates to climate change key term definition
- Updates to Figure 42.12 to use most recent data on greenhouse gas concentrations
- Revisions to "Recent increases in greenhouse gases are warming Earth's surface" subsection to address latest trends and data of extreme weather events

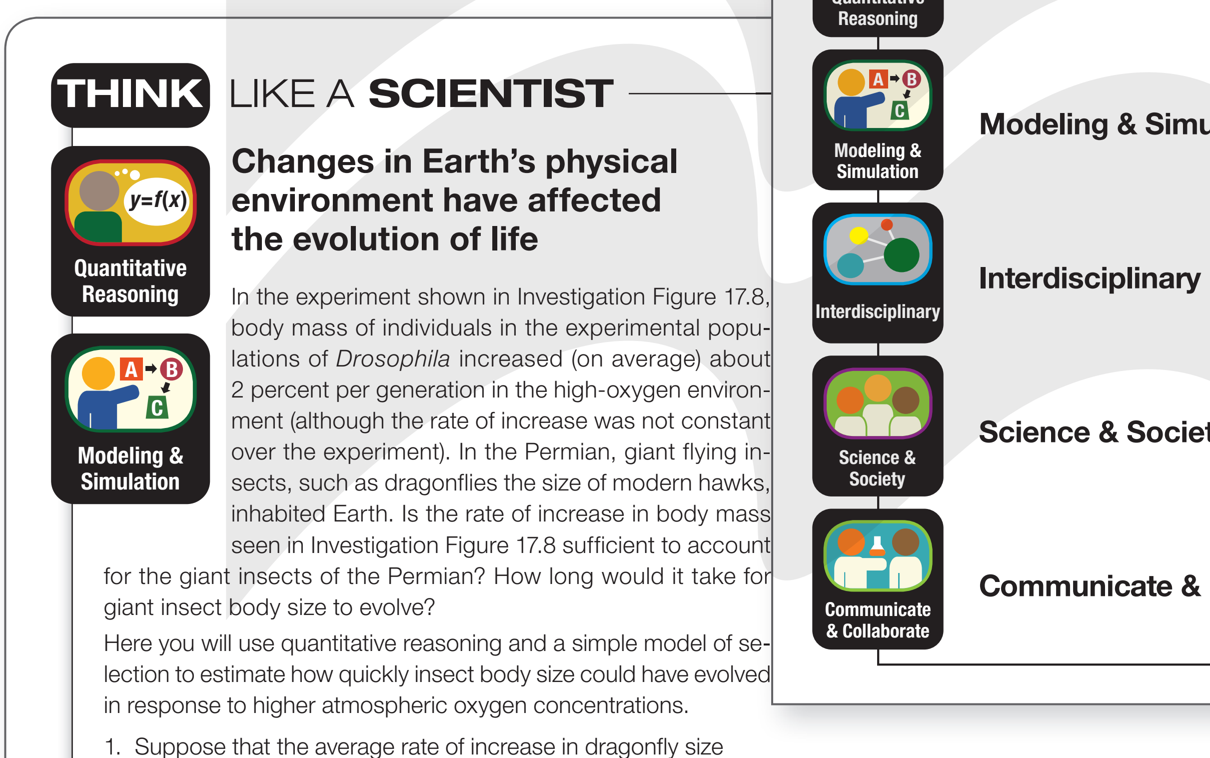
Core Competencies

***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.**

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 key feature, **THINK LIKE A SCIENTIST**.

THINK LIKE A SCIENTIST

A major goal 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*.


THINK LIKE A **SCIENTIST**

Quantitative Reasoning

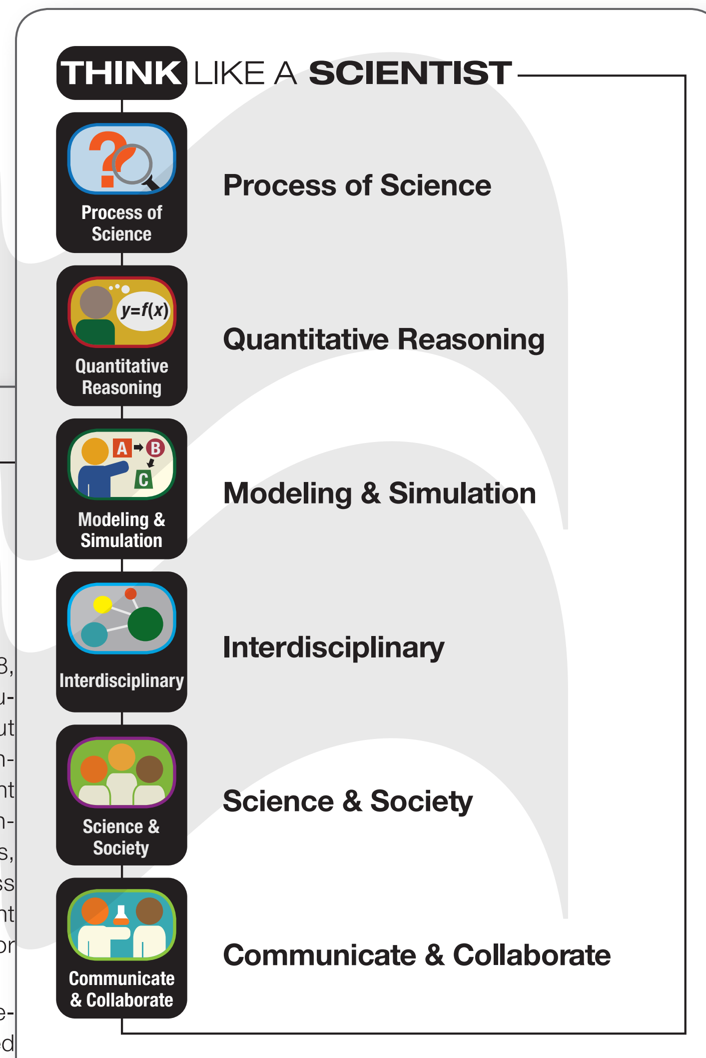
Modeling & Simulation

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



"**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."

Sara E. Lahman, PhD, *University of Mount Olive*

Core Competencies

> The **TLAS** is great. Wonderful emphasis on critical thinking and application."
> Jennifer A. Metzler, *Ball State University*

THINK LIKE A **SCIENTIST**

Science & Society

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 court case.

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?

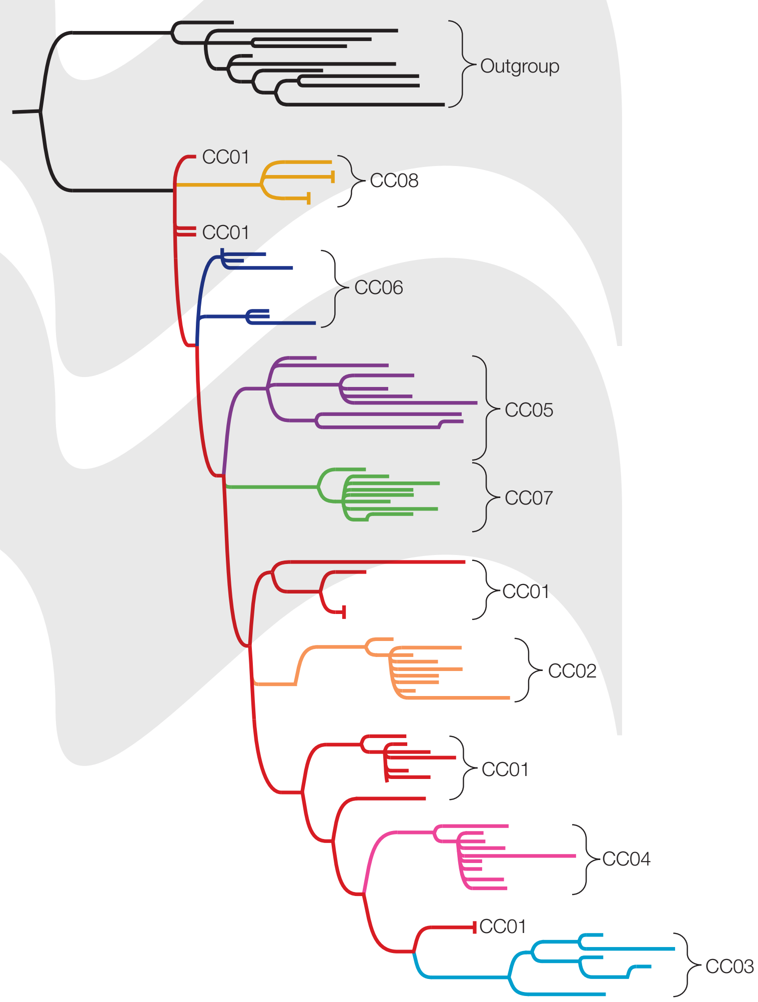


FIGURE 14.10 Forensic Phylogeny (After D. I. Scaduto et al. 2010. *Proc Natl Acad Sci USA* 107: 21242–21247.)

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 *lac* 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 *Tillandsia* 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

Quantitative Reasoning

Modeling & Simulation

Interdisciplinary

Science & Society

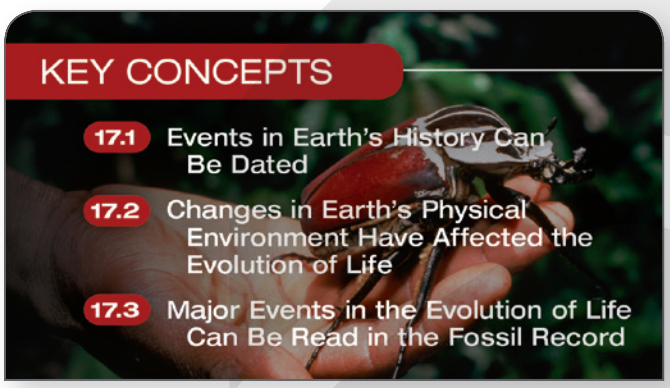
Communicate & Collaborate

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.



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

LEARNING OBJECTIVES

By the end of this key concept you should be able to:

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.

REVIEW & APPLY

This 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

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.

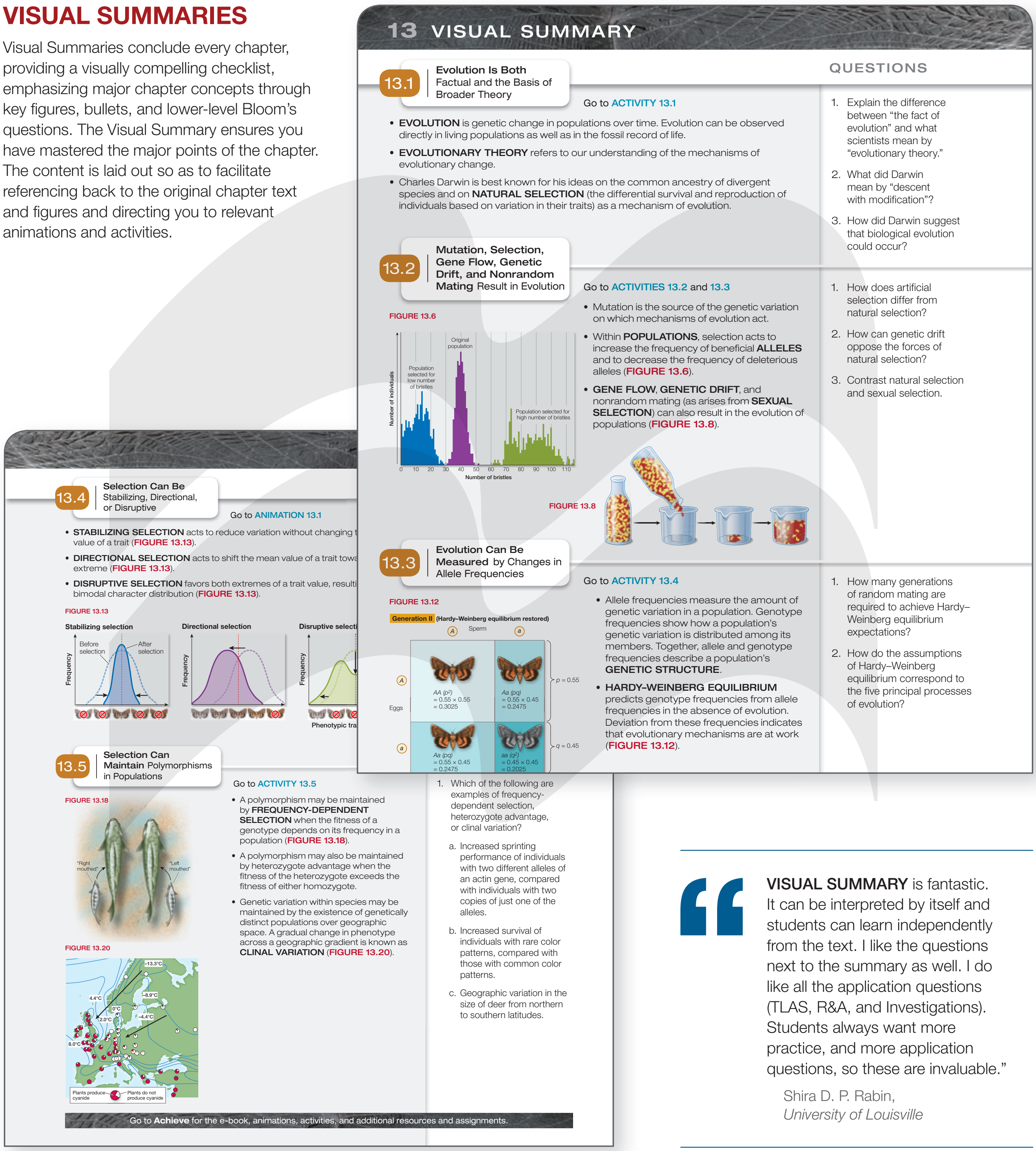
A Imagine you have been assigned the job of producing a geological map of rocks that were formed between 600 and 400 million years ago (mya). You collect a sample from each of ten sites (1–10 on the map below), determine the ratio of ^{206}Pb to ^{238}U for each sample, and use these ratios to estimate the ages of the rock samples, resulting in the table on the following page.

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

Mastering the Key Concepts

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.



13 VISUAL SUMMARY

QUESTIONS

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.

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?

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

Go to ACTIVITIES 13.2 and 13.3

FIGURE 13.6

- 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

1. How does artificial selection differ from natural selection?
2. How can genetic drift oppose the forces of natural selection?
3. Contrast natural selection and sexual selection.

13.3 Evolution Can Be Measured by Changes in Allele Frequencies

Go to ACTIVITY 13.4

FIGURE 13.12

- 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**).

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?

13.4 Selection Can Be Stabilizing, Directional, or Disruptive

Go to ANIMATION 13.1

- **STABILIZING SELECTION** acts to reduce variation without changing t[he mean] value of a trait (**FIGURE 13.13**).
- **DIRECTIONAL SELECTION** acts to shift the mean value of a trait towa[rd an] extreme (**FIGURE 13.13**).
- **DISRUPTIVE SELECTION** favors both extremes of a trait value, resulti[ng in a] bimodal character distribution (**FIGURE 13.13**).

FIGURE 13.13

13.5 Selection Can Maintain Polymorphisms in Populations

Go to ACTIVITY 13.5

FIGURE 13.18

FIGURE 13.20

- 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**).

1. Which of the following are examples of frequency-dependent selection, heterozygote advantage, or clinal variation?
   a. Increased sprinting performance of individuals with two different alleles of an actin gene, compared with individuals with two copies of just one of the alleles.
   b. Increased survival of individuals with rare color patterns, compared with those with common color patterns.
   c. Geographic variation in the size of deer from northern to southern latitudes.

Go to **Achieve** for the e-book, animations, activities, 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 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.[a]

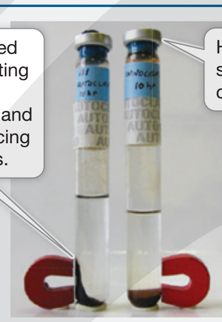
HYPOTHESIS

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 Fe^{3+} as an electron acceptor. Control tubes contain Fe^{3+} 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 Fe^{3+} to Fe^{2+} (as magnetite, which can be detected with a magnet).

RESULTS



From K. Kashefi & D. R. Lovley, 2003. *Science* 301: 934. 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, Achieve includes online companions to the Analyze the Data exercises. (See the Achieve 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:

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

Frequency of genotype $AA = N_{AA}/N$
Frequency of genotype $Aa = N_{Aa}/N$
Frequency of genotype $aa = N_{aa}/N$

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*

REVIEW & APPLY | 16.3

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)?

MAKING SENSE OF DATA: A STATISTICS PRIMER

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

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:

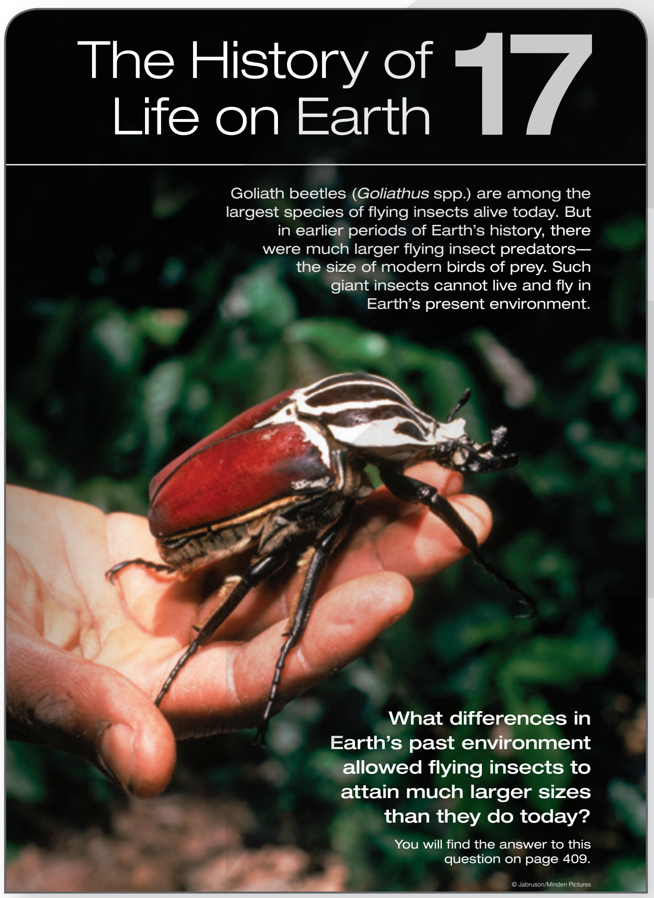
- **Step 1: Choose an Experimental Design**
  Clearly define the scientific question and the methods necessary to tackle the question.
- **Step 2: Collect Data**
  Gather information about the natural world through observations and experiments.
- **Step 3: Organize and Visualize the Data**
  Use tables,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

Active Learning

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

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.



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.

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.

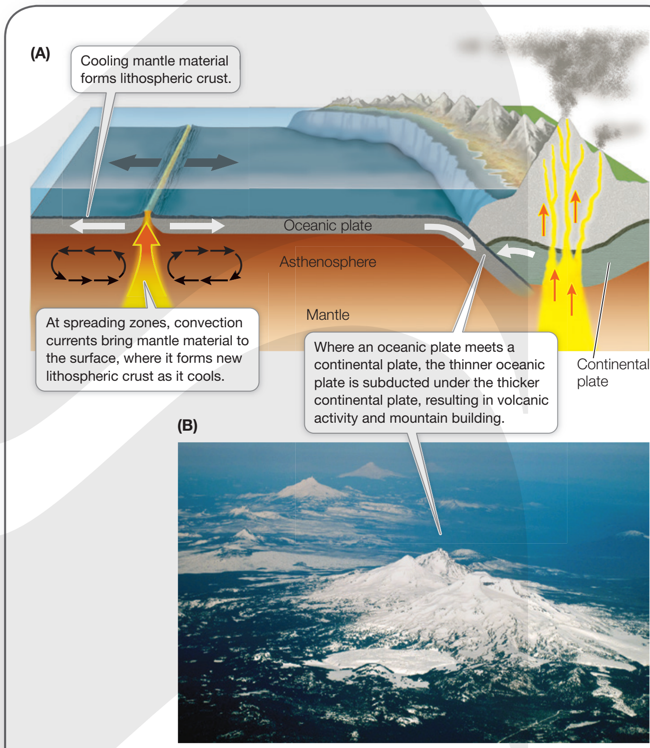


FIGURE 17.2 Plate Tectonics and Continental Drift **(A)** The heat of Earth's core generates convection currents in the viscous mantle material underlying the oceanic and continental plates. Those currents push the continental plates, along with the land masses they carry, together or apart. Where plates 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.

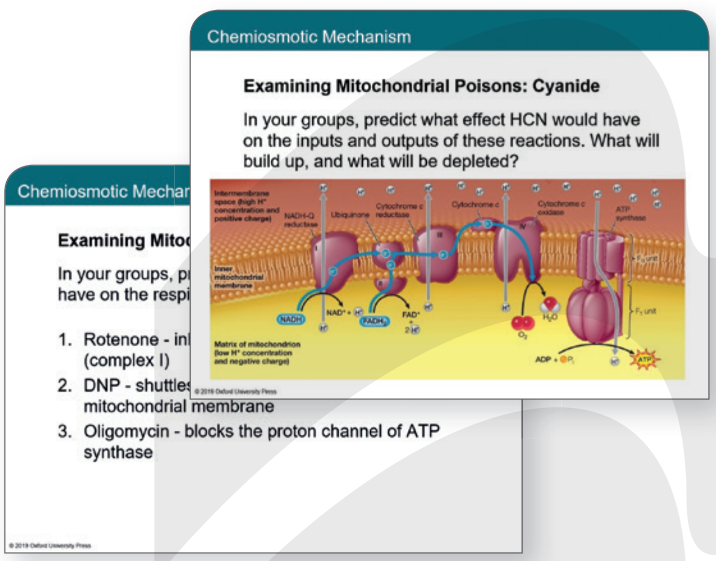
Why are both shores of the Pacific Ocean ringed with volcanic mountain ranges?
Media Clip 17.2 Lava Flows and Magma Explosions

Why are both shores of the Pacific Ocean ringed with volcanic mountain ranges?
Media Clip 17.2 Lava Flows and Magma Explosions

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.

ACTIVE LEARNING MODULES

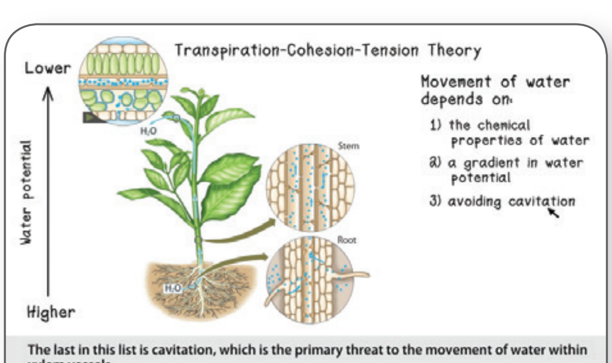


Active Learning Module In-Class Exercise Slides

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.



Active Learning Module In-Class Video

ACTIVE LEARNING GUIDE

The Active Learning Guide provides extensive resources and support for implementing active learning techniques in any classroom, large or small. This 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

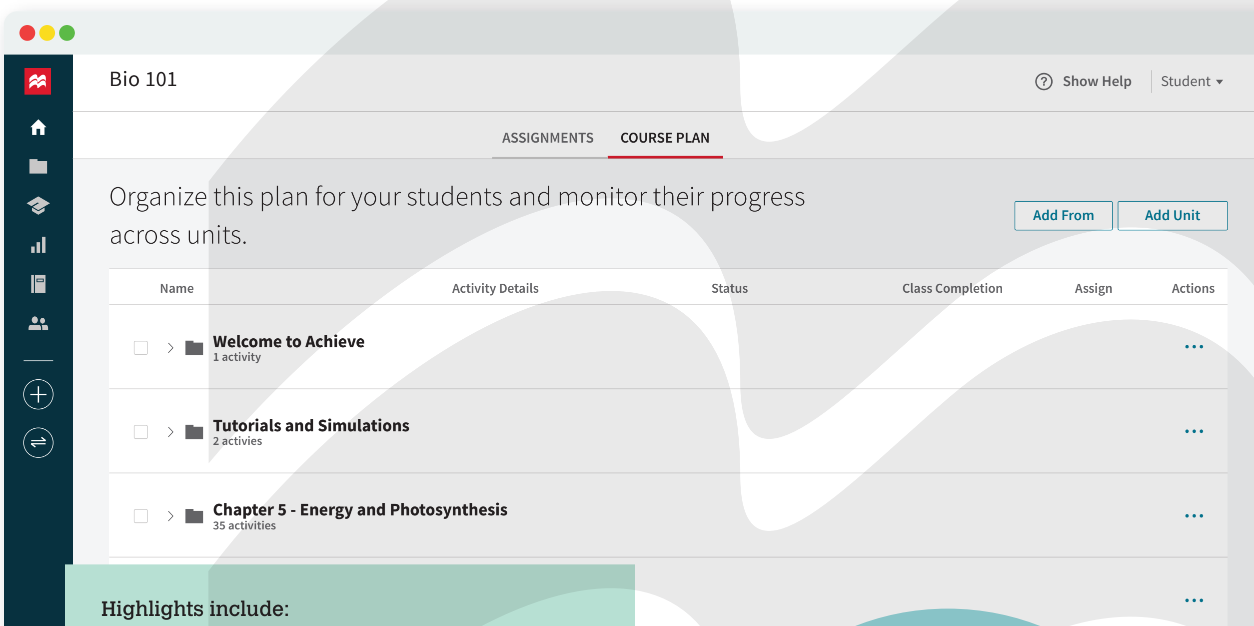
Part 3: Appendices

- 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

Principles of Life, now available with Achieve

Achieve is the culmination of years of development work put toward creating the most powerful online learning tool for biology students. It houses all of our renowned assessments, multimedia assets, e-books, and instructor resources in a powerful new platform.

Achieve supports educators and students throughout the full range of instruction, including assets suitable for pre-class preparation, in-class active learning, and post-class study and assessment. The pairing of a powerful new platform with outstanding biology content provides an unrivaled learning experience.



Highlights include:

- **A design guided by learning science research.** Co-designed through extensive collaboration and testing by both students and faculty including two levels of Institutional Review Board approval for every study of Achieve.
- **A learning path of powerful content** including pre-class, in-class, and post-class activities and assessments. A detailed Gradebook with insights for just-in-time teaching and reporting on student achievement by learning objective.
- **Easy integration and Gradebook sync** with iClicker classroom engagement solutions.
- **Simple integration** with your campus LMS and availability through **Inclusive Access** programs.

For more information or to sign up for a demonstration of Achieve, contact your local Macmillan representative or visit **macmillanlearning.com/achieve**.

Achieve: Media and Assessment Resources

Principles of Life's assessment and media resources give instructors a range of tools for assessing student's progress before class, in class, after class, and on exams.

Assessment questions and resources are aligned to the Learning Objectives associated with each Key Concept. This provides instructors with a concrete way of assessing students on mastery of the most important material in each chapter.

FEATURE	ASSESSMENT AND MEDIA RESOURCES
Active Learning Modules	Active Learning modules include everything needed to conduct in-class activities. Resources include pre- and post-class quizzes, videos, student handouts, and instructor activity guides.
Learning Curve	LearningCurve adaptive quizzing gives students individualized question sets and feedback based on responses. All questions link back to the e-book to encourage students to read the book in preparation for class and exams. LearningCurve organizes questions by Key Concept, and instructors can easily hide questions on concepts they are not covering. New questions have been added to Learning Curve for the Third Edition Digital Update.
Activities & Simulations	Interactive activities, including simulations, are assignable and include assessment questions for students to check their understanding.
Analyze the Data	Each in-text Analyze the Data exercise is accompanied by an online companion exercise. The online companion exercise gives additional practice with the same skills addressed by the in-text exercise.
Animations	Animations with associated questions to help students visualize important concepts.
Summative Quizzes	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.
Test Bank	The *Principles of Life* Test Bank available in Cognero includes new questions added for the Third Edition Digital Update. Questions are offered at a variety of Bloom's levels and cover all key concepts in the text.
Achieve Item Library	The Achieve item library allows instructors to create their own assignments and author their own questions. Easily search for questions and filter by difficulty level, Bloom's level, grading, or question type or topic. *Principles of Life*, Third Edition Digital Update, includes many new questions, including kinesthetic type questions.

Preface

Principles of Life, Third Edition Digital Update

Principles of Life, Third Edition, is updated and now available with Achieve! Achieve supports students and educators throughout the full range of instruction, including assets suitable for pre-class preparation, in-class active learning, post-class study and assessment. The pairing of a powerful new platform with outstanding biology content provides an unrivaled learning experience.

Features of Achieve Include

- A design guided by learning science research. Developed with extensive collaboration and testing by students and faculty, including two levels of Institutional Review Board approval for every efficacy study of Achieve.
- A learning path of powerful content including pre-class, in-class, and post-class activities and assessments.
- A detailed Gradebook with insights for just-in-time teaching and reporting on student achievement by learning concept.
- Easy integration and Gradebook synchronization with iClicker classroom engagement solutions.
- Simple integration with your campus LMS and availability through Inclusive Access programs.

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 a 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.

The conception of *Principles of Life* coincided with two major reports that supported the change to a conceptual approach; *Vision and Change in Undergraduate Biology Education: A Call to Action*, published in 2011 by the American Association for the Advancement of Science (supported by the National Science Foundation) 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.

With the astute guidance of Andy Sinauer—we convened an advisory group of twenty leading biology educators and instructors in introductory biology from throughout North America. During an intensive meeting of the authors and this group, dynamic discussions led to the solidification of the core concepts we believe are essential for teaching introductory biology. The book took shape, and members of the advisory group reviewed the emerging chapters, providing feedback at every stage of the book's development.

All chapters have undergone extensive between-edition review by experts in each respective discipline, and the chapters have been revised accordingly. Active learning has always been a priority in *Principles of Life*. With the Third Edition revised, 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 systems concepts is expanded. With the *Think Like a Scientist* feature, we have developed opportunities for students to practice the core competencies that have become critical for modern biologists.

Principles of Life stresses the five core concepts (themes) identified in *Vision and Change* as being essential for all undergraduates to understand:

- 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 concepts, 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* 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.

Vision and Change, in addition, identified six core competencies that undergraduates must develop to succeed in science in the twenty-first century. *Principles of Life* and Achieve support students in developing these skills. *Vision and Change* argues 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, and
- understand the relationship between science and society.

Our art program for *Principles of Life* continues to build on our success from *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 help students connect critical points of figures to the concepts that are developed in the text. Conceptual diagrams are used in many places, and text-art coordination has been emphasized. 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.

Features of *Principles of Life*

Focus on Concepts: Each chapter is organized into a series of *Key Concepts*, each with its own *Learning Objectives*. Our focus in each Key Concept section is to identify and explain the concepts that beginning university students need to know. At the end of each Key Concept, a *Review & Apply* 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 further questions related to the Learning Objectives. Throughout, the questions we raise are deliberately designed to span the incremental levels of Bloom's Taxonomy of Cognitive Domains. Answers to all questions are included in Achieve, *Principles of Life*'s online platform.

Chapter Opener: Each chapter starts with carefully worded, professionally vetted *Learning Objectives*, which are then reinforced with each Key Concept section in the chapter, so that students can clearly see the goals they will achieve in their studies. Chapter openers have been designed with active learning in mind. Each chapter begins with a brief statement focused on major themes accompanied by a dramatic photograph and interpretive question 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.

Think Like a Scientist: The *Think Like a Scientist* entry in each chapter emphasizes one or more of the six core competencies, using a system of 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 will help each student learn more about the ways that scientists think. Questions—with answers at our online companion site, Achieve—are often provided to stimulate engagement.

Investigations: Investigations help students learn the process of science by being organized into sections on Hypothesis, Method, Results, and Conclusion. Most include a section (titled *Analyze the Data*) in which we present a subset of actual data from the published experiment. Students are asked to analyze these data and to make connections between observations, analyses, hypotheses, and conclusions. Extensive online resources are provided to expand the content on many Investigations. These resources include expanded discussions of the original research, links to the original publications, and discussion and links for any follow-up investigations that have been published. We have also included a *Making Sense of Data: A Statistics Primer* (Appendix B) to help students in developing this important skill.

Review and Apply: Each section concludes with 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 online in Achieve.

Visual Summary: 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 in Achieve.

Media Links: 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. The *Links* are not merely cross-references but include brief statements of pertinence, helping readers to see why they might want to follow a *Link*. We also feature *Animated Tutorials* and *Activities*, which include opportunities for students to use modeling and simulation modules to further reinforce their understanding of concepts.

Research Tools: Students need to learn about some of the major research tools that are used in biology, including major laboratory, computational, and field methods. Our *Research Tools* figures explain these tools and provide a context for how they are used by biologists. We have also included a *Working with DNA* so that students have an easy place to review and understand the major methods of molecular biology.

Active Learning: Active learning is a key component of *Principles of life*. We have implemented opportunities for active learning throughout the text and online in Achieve. In-text active learning opportunities include chapter opening questions, which give students something to ponder when reading and studying the chapter. Figure questions are designed to engage students and help them think about the implications of the figure or diagram. Active Learning modules include resources for classwork, as well as an instructor guide to support instructors in implementation of active learning.

Special Contributions

Many people contributed to the creation of the Third Edition Digital Update of *Principles of Life* (see below). However, three individuals deserve special mention 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).

Many People to Thank

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 issues and made critical suggestions for new material. They are: Walter Arnold, University of Veterinary Medicine (Vienna); Tobias Baskin, University of Massachusetts; Larry Gilbert, University of Texas, Austin; Harry Greene, Cornell University; Hugo Hofhuis, Wageningen University; 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); Richard Shingles, Johns Hopkins University; David Sleboda, Brown University; Viola Willemsen, Wageningen University; and Andrew Zanella, The Claremont Colleges.

Special thanks go to our editors who have guided us and the book through to the completion of the Third Edition Digital Update: Lisa Lockwood, Debbie Hardin, Marita Bley, Andy Sinauer, Danna Niedzwiecki, and Laura Green. 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. We also wish to thank the entire team at Macmillan, including the Macmillan media group for their expertise in producing Achieve, the Regional Specialists, and the Regional Sales Managers.

Digital Content and Supplements

Principles of Life features a wide array of online resources to support and reinforce the material covered in the textbook. The activities, animations, and media clips referenced throughout the book are linked directly in the e-book, allowing students to instantly reference these resources from any device.

There is a wide array of instructor resources available, including multiple versions of all textbook figures, PowerPoint presentations, and a computerized test bank. PowerPoints and images are available from within Achieve, as well as the Active Learning Guide and Instructor's Manual. The computerized Test Bank can be accessed from the Instructor's Companion site.

We have enjoyed writing *Principles of Life* and wish you success. We hope that this book will serve you well.

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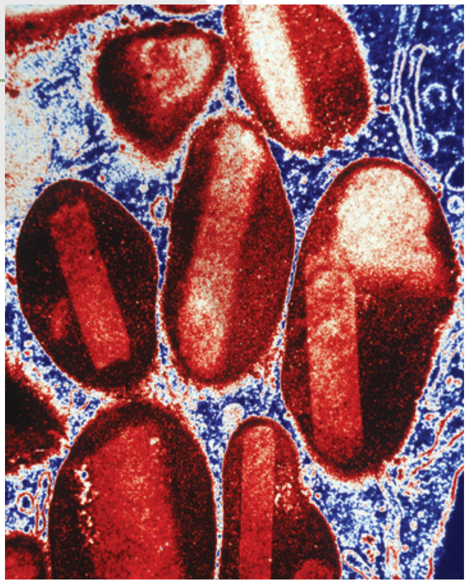

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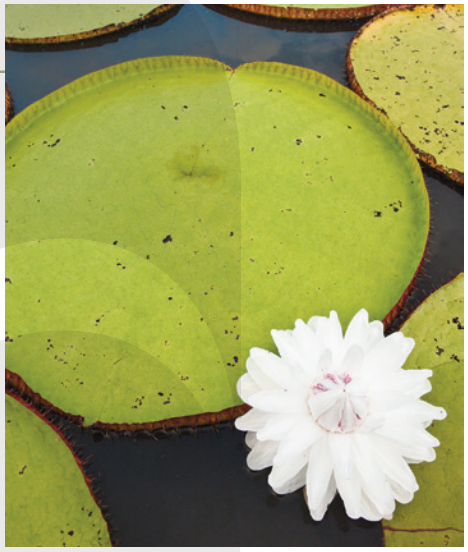

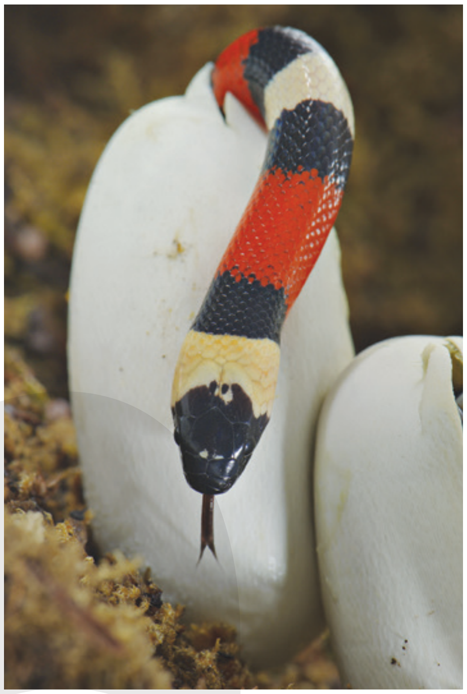

Part 7 Ecology


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