Life

The Science of Biology

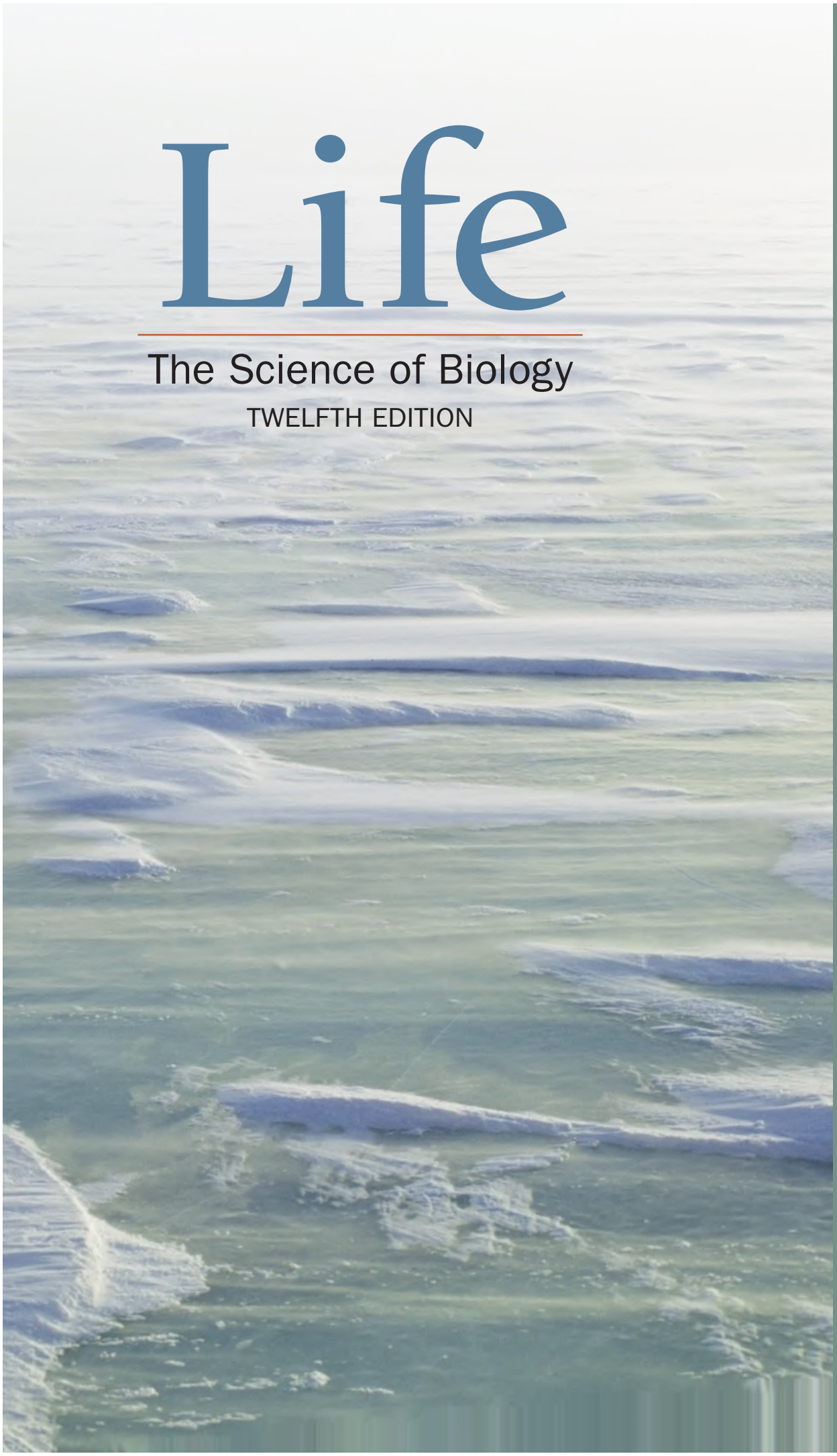
TWELFTH EDITION

HILLIS • HELLER • HACKER • HALL • LASKOWSKI • SADAVA

Life

The Science of Biology

TWELFTH EDITION



Life

The Science of Biology

TWELFTH EDITION

David M. Hillis
University of Texas, Austin

H. Craig Heller
Stanford University

Sally D. Hacker
Oregon State University

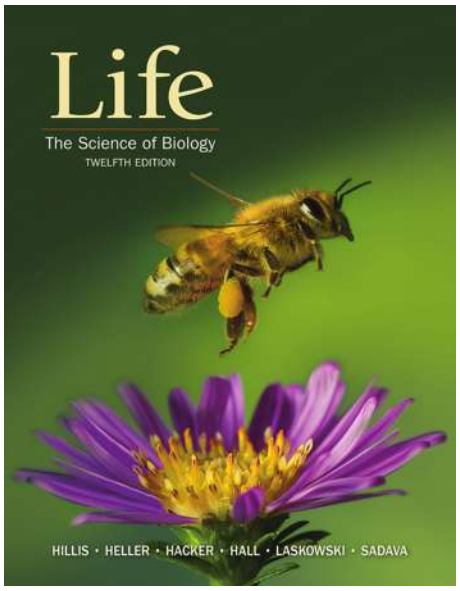
David W. Hall
University of Georgia

Marta J. Laskowski
Oberlin College

David Sadava
Emeritus, The Claremont Colleges

SINAUER

MACMILLAN



The Cover
See the inside front cover for an explanation of the honey bee.
Photo © Michael Durham/Minden Pictures.

The Frontispiece
Polar bear (*Ursus maritimus*) and arctic fox (*Alopex lagopus*) on an ice field, Hudson Bay, Churchill, Manitoba, Canada. Photo © Thomas Mangelsen/Minden Pictures.

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.

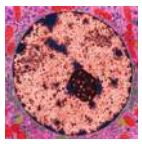
Examination Copy Information: 1-800-446-8923

Library of Congress Cataloging-in-Publication Data
Names: David M. Hillis, author.
Title: Life: the science of biology / David M. Hillis, University of Texas, Austin, H. Craig Heller, Stanford University, Sally D. Hacker, Oregon State University, David W. Hall, University of Georgia, Marta J. Laskowski, Oberlin College, David Sadava, Emeritus, The Claremont Colleges.
Description: Twelfth edition. | Sunderland, MA : Sinauer Associates/ Macmillan, [2020] | Includes index.
Identifiers: LCCN 2019021338 | ISBN 9781319017644 (case-bound)
Subjects: LCSH: Biology--Textbooks.
Classification: LCC QH308.2 .L565 2020 | DDC 570--dc23
LC record available at https://lccn.loc.gov/2019021338

Printed in the United States of America
First Printing December 2019
Printed by LSC Communications

Contents in Brief

PART ONE
The Science of Life and Its Chemical Basis



PART TWO
Cells

PART THREE
Cells and Energy

PART FOUR
Genes, Genomes, and Heredity

PART FIVE
The Processes and Patterns of Evolution

PART SIX
Diversity of Life

PART SEVEN
Flowering Plants: Form and Function

PART EIGHT
Animals: Form and Function

PART NINE
Ecology

PHOTO CREDITS:
Table of Contents in Brief: Part One: © National Geographic Image Collection/Alamy Stock Photo, Part Two: © Dennis Kunkel Microscopy/Science Source, Part Three: E. Stone. 1763. Philos Trans R Soc Lond 53: 195–200, Part Four: © Steve Gschmeissner/Science Source, Part Five: © blickwinkel/Alamy Stock Photo, Part Six: "Milky seas" data prepared by Steven Miller of the Naval Research Laboratory, Monterey, CA. Background data (Earth at Night image) courtesy Marc Imhoff (NASA/GSFC) and Christopher Elvidge (NOAA/NGDC); image by Craig Mayhew (NASA/GSFC) and Robert Simmon (NASA/GSFC)., Part Seven: © MisoKnitl/Getty Images, Part Eight: © dpa picture alliance/Alamy Stock Photo, Part Nine: © Morley Read/Alamy Stock Photo.

Life The Science of Biology

Dear Instructor,

Biology inspires wonder. The image of a honey bee pollinating an aster [*Symphyotrichum* sp. (*Asteraceae*)] on our cover shows an example of mutualism between a plant and an animal. The plant needs the bee to successfully reproduce, and the bee gets nectar and pollen from the plant for food. This fascinating relationship is an example of what motivates biologists to study the complexities and interactions of life.

Biology is dynamic. It is constantly changing as new insights lead to new ideas and new tools to test those ideas. Think of the use of drones and satellites to photograph penguin populations in Antarctica. Think of the developments in biological imaging and computation. Think of genome sequencing and its effect on our understanding of everything from human diseases to the tree of life. Think of the use of ice cores to understand past global climate.

Biology is a system. Biological systems are made up of different levels of organization—from molecules to ecosystems—that are interconnected and complex. Biologists are beginning to use integrated approaches to understand the complex properties of biological systems.

Biology is life. We face many challenges as humans, including emerging diseases, feeding people in a sustainable way, population growth, degradation of natural systems, and climate change. We understand that humans are integrally connected to and dependent on all life on Earth.

Our goal—and challenge—in writing *Life* is to engage students in all these aspects of biology by motivating learning through active discovery. We focus on key concepts and contemporary examples that provide a foundation for further study. We have consulted and collaborated with faculty, students, and experts in the fields of biology and education. As you will see in the next several pages, in this, our Twelfth Edition, we engage students by explaining how biology affects their daily lives and how new knowledge is discovered. To help students master the concepts and principles of biology, we have continued to develop and expand our active learning activities.

For more information or to request your review copy, contact your local Macmillan Learning representative or visit www.macmillanlearning.com/Life12e

In the new edition of *Life: The Science of Biology*, you'll find

the book's signature focus on skill-building, engagement, and active learning taken to a whole new level. With extensive updating, new pedagogical features, and powerful online advances in **Achieve**, it immerses students in the world of biological experimentation, providing impactful experiences with research and data they'll need to succeed in class and in their future STEM careers.

Life The Science of Biology is

FOCUSED ON SKILLS

To support teaching and learning in biology through asking questions:

- **New!** **Data in Depth** is a new online feature that offers students hands-on practice with key data skills. Companions to the in-text **Work with the Data** feature, these exercises help build students' data literacy and data manipulation skills through a range of interactive elements and assignable questions.
- Engaging and powerful **simulations** let students interact with important biological processes. They can be used as a tool in lectures or as homework assignments. The simulations now include quizzes that report to the **Achieve** gradebook.
- **New!** The online version of Appendix B, **Making Sense of Data: A Statistics Primer** gives students the opportunity to learn basic statistical concepts and skill through hands-on simulations and activities.
- The **Experiments** and **Work with the Data** exercises highlight important research and **instill the foundation of scientific investigation in students** by always following the hypothesis–method–results–conclusion framework.
- Questions in **Recap and Assess** range from questions that support retention of content to questions that foster higher-order thinking.
- Leading by example, *Life* exposes students to many thoughtful questions throughout the body of the text, **reinforcing the importance of asking questions** in biology.
- To make sure students get the most out of the multitude of questions available to them in the textbook, **answers to all in-book questions are included in Achieve**.

FOCUSED ON ENGAGEMENT

To help students take learning into their own hands:

- The **Investigating Life** narrative thread **weaves through the chapter** to keep students engaged from the first page to the last. In every chapter the opening story and question set the stage for the narrative, a related **Experiment** and **Work with the Data** exercise helps reinforce the concepts, and the **Future directions** feature at the end helps wrap up the investigation.
- **References** to media such as animations, simulations, and jaw-dropping videos appear throughout each chapter and **allow students to interact with content in a variety of ways**.
- Intriguing questions in figure captions **sharpen students' skills in critical thinking** about biology and subtly reinforce the process of doing science.
- **Connect the Concepts** foster **thinking about the big picture**—a task that can be overwhelming for introductory biology students—by demonstrating how certain important terms and concepts relate to discussions in another chapter.

FOCUSED ON ACTIVE LEARNING

To help instructors encourage students to "learn by doing":

- The **Active Learning Guide** (for instructors) provides invaluable resources and support for **implementing active learning techniques in the classroom**. Accompanying the Guide are a set of full **Active Learning Modules**, which are comprised of a pre-lecture video, a complete in-class exercise, a pre- and post-quiz, and extensive instructor support.
- **Learning objectives guide students to the essential content** as they read through each **Key Concept** section.
- **Recap and Assess** for each **Key Concept** includes **questions** (all Bloom's levels 2–4) that test students' mastery of the **Key Concept**.

EXPERIENCED THROUGH ACHIEVE

With this edition's **Achieve**, *Life* is more than ever a truly integrated text/media resource. **Achieve** gives students everything they need to prepare for class and exams while giving instructors everything they need to set up a course, customize the content, craft presentations, assign homework, assess students, and guide the progress of individuals and the class as a whole.

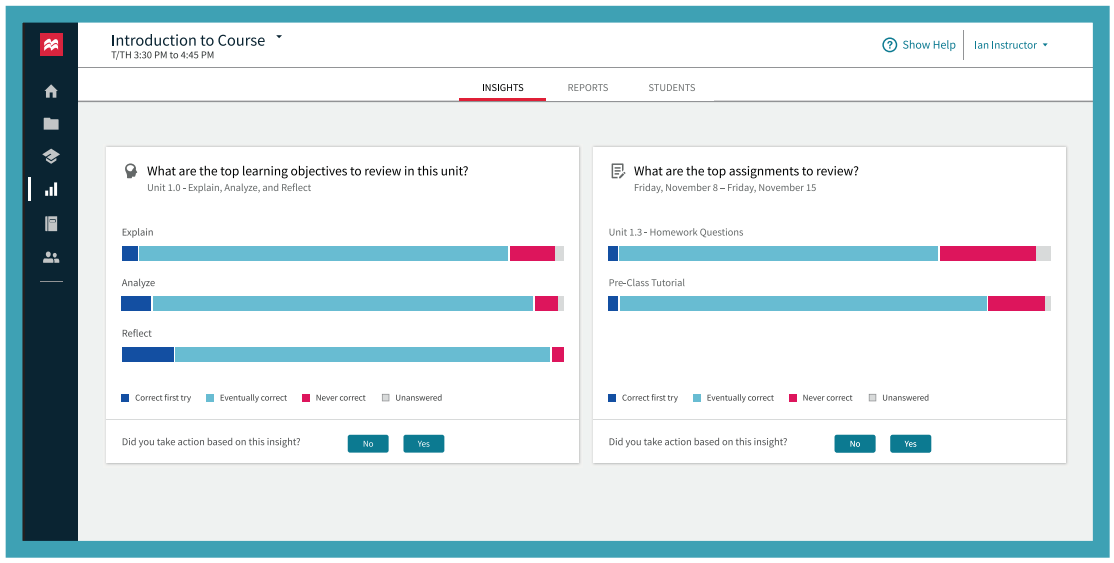
Life The Science of Biology
Achieve for *Life*

Introducing

Achieve

achieve.macmillanlearning.com

ACHIEVE is a comprehensive set of interconnected teaching and assessment tools. It incorporates the most effective elements from Macmillan's market leading solutions—including LaunchPad, iClicker and others—in a single, easy-to-use platform. Our resources were co-designed with instructors and students, using a foundation of learning research and rigorous testing.



ENGAGING STUDENTS FOR BETTER OUTCOMES

Students interact more meaningfully with content when using Achieve.

SUPPORTING STUDENTS OF ALL LEVELS

Achieve was designed for all students whether they are high achievers or need extra support.

PARTNERING WITH YOU

Macmillan remains dedicated to expert authorship and support of the customer experience.

★ For every 1% increase in the proportion of Achieve pre-class activities a student completes, she can expect a 1% increase in her final course grade.

↑ **8%** Students who completed at least 81% of their pre-class activities scored 8% higher on their final exams.

This finding is true for all students—those less and more academically prepared to succeed.

88% 88% of students (1,241 students) reported that Achieve activities were engaging.

Life The Science of Biology
Achieve for *Life*

Achieve for *Life* features:

INSIGHTS & REPORTING

Powerful analytics, viewable in an elegant dashboard, offer instructors a window into student progress.

RESOURCES

Achieve includes access to carefully developed, book-specific content as well your own resources to use in the course as needed.

E-BOOK

The e-book offers highlighting, note-taking, offline access, and read aloud functionality.

DIVERSE, THOUGHTFUL QUESTIONS

Multiple question types enhance student engagement and critical thinking skills.

GRADEBOOK

An easy-to-use gradebook provides a clear window into performance for the whole class, for individual students, and for individual assignments.

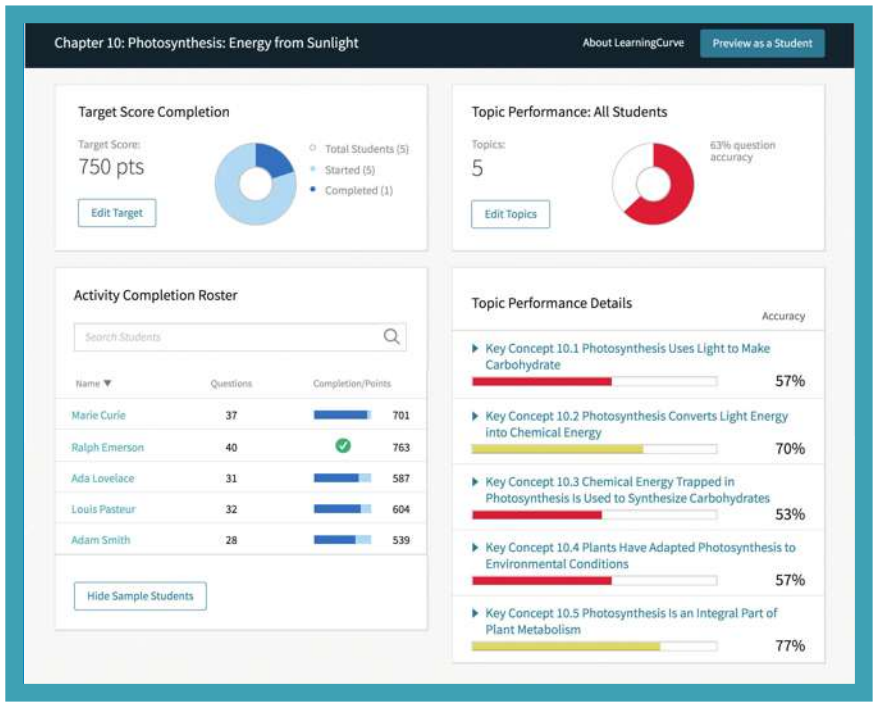
INTEGRATION OPTIONS

You can work with us to integrate with your campus LMS—including Blackboard, Canvas, D2L/Brightspace, Moodle—as well as for Inclusive Access.

COURSE- & DISCIPLINE-SPECIFIC TOOLS

Depending on the discipline, Achieve also includes:

- Diagnostics
- Writing and revision tools
- A math assessment engine
- Molecular drawing software
- and more.



Learn more about the research that went into the development of Achieve at **macmillanlearning.com/achieve**.

All students benefit from Achieve, but especially those who are less academically prepared.

↑ +12 There is a 12 percentage point boost in final exam scores for students who were less academically prepared.

↑ +9 There is a 9 percentage point boost in final exam scores for all students when they hit 81% completion of Achieve assignments.

↑ +6 There is a 6 percentage point boost in final exam scores for students who were more academically prepared.

Life The Science of Biology Focused on Skills

Developing Skills and Working with Data

Life has always been known for emphasizing the role of experimentation, data, and research in our understanding of biology.

The **Experiments** and **Work with the Data** exercises highlight important research and **instill the foundation of scientific investigation in students** by always following the hypothesis–method–results–conclusion framework.

> I especially like the **Work with the Data** exercises. Too often this sort of critical thinking is left to upper-level courses."
>
> —Susan Reigler, Indiana University Southeast

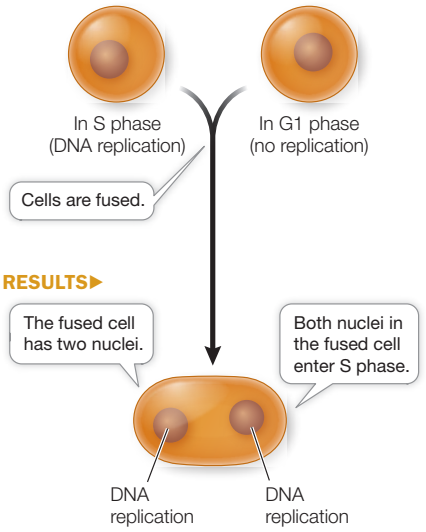
Experiment

Original Paper: P. N. Rao and R. T. Johnson. 1970. Mammalian cell fusion: Studies on the regulation of DNA synthesis and mitosis. *Nature* 225: 159–164.

Nuclei of cells in G1 do not undergo DNA replication, but nuclei in S phase do. Rao and Johnson wondered whether substances present in cells in S phase could be used to induce DNA replication in cells in G1.

HYPOTHESIS▶ A cell in S phase contains an activator of DNA replication.

METHOD▶



CONCLUSION▶ The S phase cell contains a substance that diffuses to the G1 nucleus and activates DNA replication.

Work with the Data

The fusion of cellular membranes is a natural process; it occurs during endocytosis and exocytosis, and in fertilization (the fusion of gametes). Membrane fusion also occurs when membrane-enclosed viruses infect their host cells. Occasionally these viruses also induce the fusion of adjacent host cells, creating a multinucleate cell. This observation led to the use of Sendai virus, a membrane-enclosed mouse respiratory virus, as a tool in the laboratory to fuse cells experimentally. Rao and Johnson used this strategy to study the regulation of the cell cycle.

In their experiment, Rao and Johnson used HeLa cells, which divide continuously (see the opening story of this chapter). First, they isolated cells in either G1 or S phase. Before fusion, the cells in S phase were exposed to a radioactively labeled component of DNA (thymidine). The radioactivity was incorporated into these cells' newly replicated DNA, labeling their nuclei. The S and G1 cells were then fused using Sendai virus (resulting in G1/S fusions) and again exposed to labeled thymidine. At various times after fusion, the scientists calculated the percent of previously unlabeled (G1) nuclei that had incorporated new label (i.e., had replicated their DNA) (**Figure A**). In a second series of experiments, S and G2 cells were fused in various combinations and then the numbers of cells in mitosis were counted and expressed as a percent of all cells in the population (**Figure B**).

Figure A

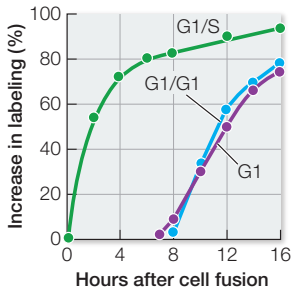
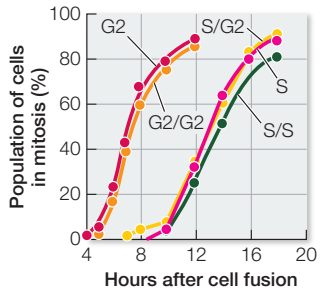


Figure B



QUESTIONS▶

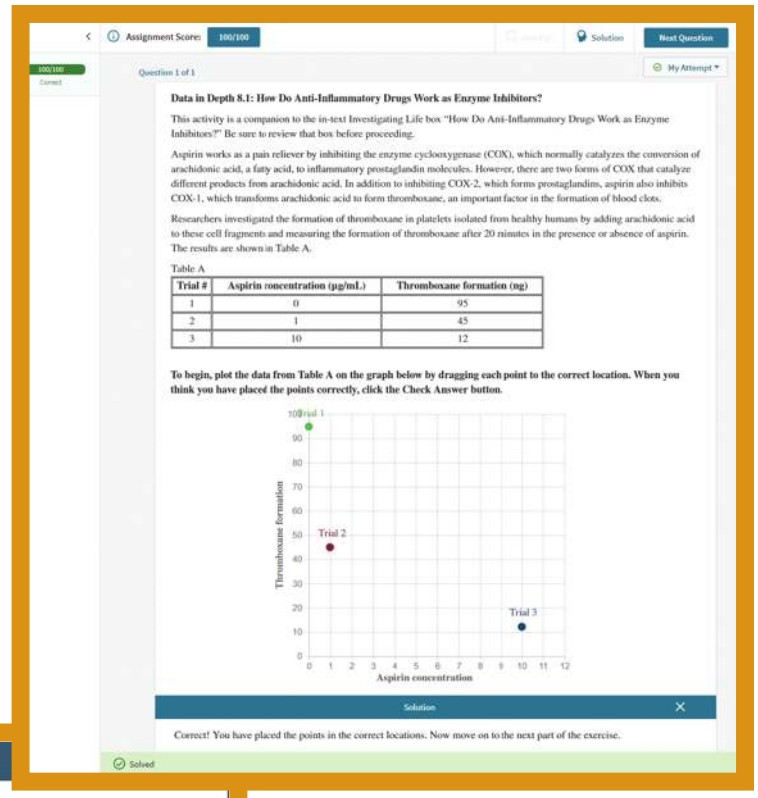
1. According to Figure A, how long did it take for all the G1 nuclei in the G1/S cells to become labeled?
2. Examine the data for fused G1/G1 cells and unfused G1 cells in Figure A. Explain why these were appropriate controls for the experiment. When did these nuclei become labeled? Compare these times with each other and with that for the G1/S nuclei and discuss.
3. Examine the data in Figure B. Why did it take longer for the S phase cells to begin mitosis than the G2 cells?
4. According to Figure B, did fusion with G2 cells alter the timing of mitosis in the S cell nuclei? Explain what this means in terms of regulation of the cell cycle.

Go to Achieve for a companion Data in Depth exercise.

Life The Science of Biology
Focused on Skills

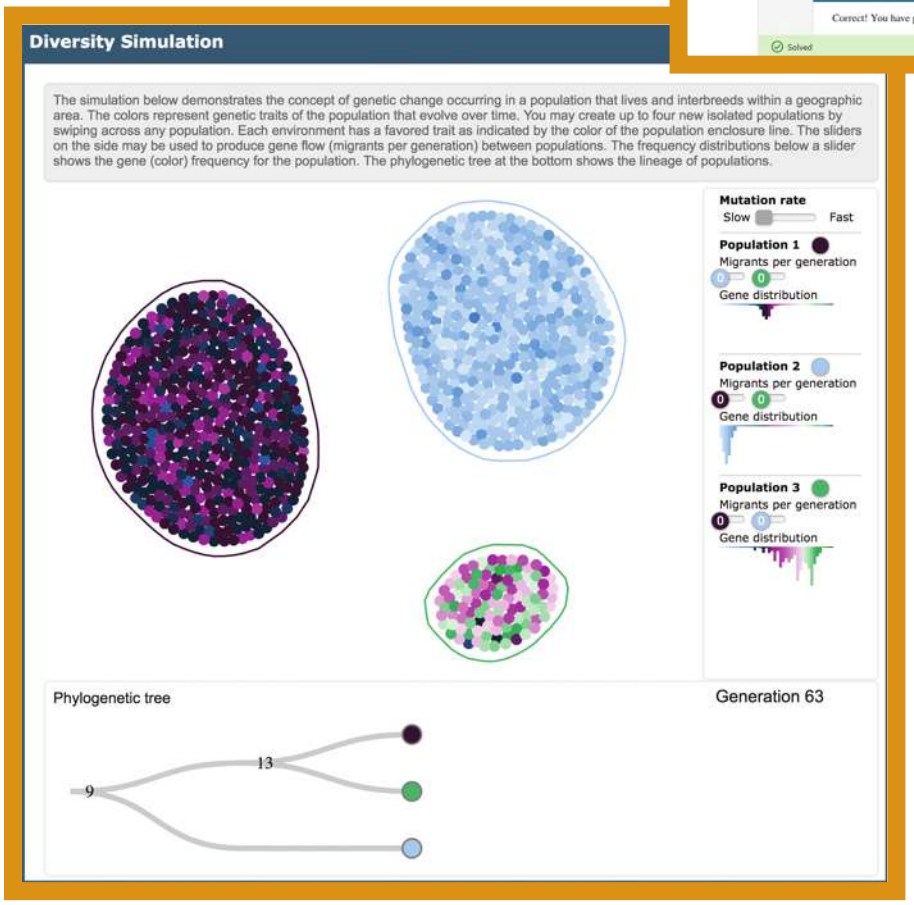
New Digital Feature in **Achieve**! Data in Depth

Data in Depth is a new online feature that offers students hands-on practice with key data skills. Companions to the in-text **Work with the Data** feature, these exercises help build students' data literacy and data manipulation skills through a range of interactive elements and assignable questions.



Simulations

The engaging and powerful simulations in **Achieve** allow students to interact with important biological processes. They can be used as a tool in lectures or as homework assignments. The simulations now include quizzes that report to the gradebook in **Achieve**.



Life The Science of Biology
Focused on Engagement

New! Visual Summaries

Visual Summaries conclude every chapter, providing students with a visually compelling checklist, emphasizing major concepts through key figures, bullets, and mid-range Bloom's questions. To ensure mastery of the Key Concepts, the summary encourages students to refer to the original chapter text and figures, and to relevant animations and activities.

VISUAL SUMMARY 57

You should be able to relate each summary to the adjacent figures. If you go to this visual summary in **Achieve**, you can follow links to figures, animations, activities, and simulations that will help you consolidate the material.

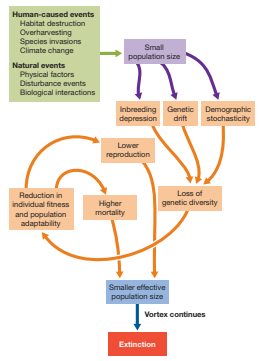
KEY CONCEPT
57.1 Human Activities Are Changing the Biosphere, Resulting in Biodiversity Loss

- Biodiversity has great value to human society in the form of goods and services, but human activities have caused its rapid decline at genetic, population, species, ecosystem, and global scales.
- Human-caused events coupled with natural events can reduce a species' **effective population size** (number of individuals that can contribute offspring to the next generation), leading to population and species extinctions. Ever-smaller effective population sizes are affected by inbreeding depression, genetic drift, and **demographic stochasticity**.
- Humans are causing biodiversity loss at unprecedented rates, rivaling that of the five previous mass extinction events, which were the result of cataclysmic natural disasters.
- We can estimate the extinction probability of species by taking into account their population sizes, genetic variation, life history traits, and ecology.

Questions

1. How does the loss of biodiversity at one scale affect its loss at other scales?
2. How can reducing a species' effective population size result in population and species extinction?
3. Why is it difficult to determine how many species are extinct, and what factors indicate that a species could be at risk of extinction?

Figure 57.2

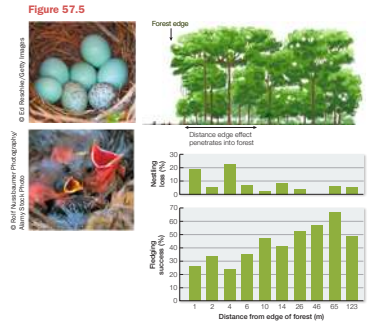


KEY CONCEPT
57.2 Most Biodiversity Loss to Date Is Caused by Habitat Loss and Degradation

Go to **Animation 57.1**

- **Habitat loss** (reduction in habitat quantity) and **habitat degradation** (reduction in habitat quality) have been the major causes of biodiversity loss. Estimates are that humans have transformed and fragmented 50%–60% of the land surface, primarily for agriculture, timber, and livestock grazing.
- Overharvesting of species for food, clothing, ornamentation, pets, and medicines was once the most important and rapid cause of species extinction and is still a concern for some species, and their food webs, if conservation measures are not enacted.
- Deliberate or inadvertent introductions of non-native species have increased exponentially over the last 200 years, with roughly 10% of those species becoming invasive.
- **Invasive** species can endanger native species through predation, competition, and disease. They can cause changes to ecosystem functions or genetic diversity through hybridization with wild populations.
- Human-generated emissions of greenhouse gases are contributing to global climate warming, sea level rise, increased storminess, and ocean acidification, all of which are becoming increasingly important causes of biodiversity loss.

Figure 57.5



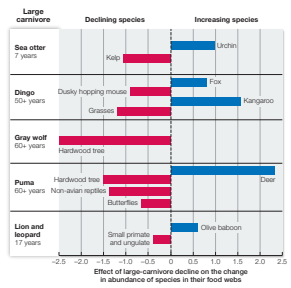
VISUAL SUMMARY 57

- Scientific evidence shows that some species have been, or are currently being, affected by climate change through distributional changes, timing of life history events, and decreased growth and reproduction.

Questions

1. How do habitat loss, degradation, and fragmentation contribute to the extinction of species?
2. Give three reasons why invasive species can have negative effects on biodiversity and ecosystems.
3. Describe how overharvesting and climate change could affect a large carnivore species and its food web.

Figure 57.9



…cting Biodiversity Requires Conservation …Management Strategies

Go to **Activity 57.1** and **Animation 57.2**

…ientific theory, empirical data, and tools from a variety …elp inform socioeconomic and institutional sectors in …d management of biodiversity.

…ed areas and restoring degraded habitat can curtail …Creating viable protected areas requires establishing …s, buffer zones surrounding them, and habitat corridors

…logy involves renewing degraded ecosystems by re- …original structure and function through active removal …n-native species, revegetation to reestablish habitat …es, reintroduction of native species, or reestablishment …esses such as disturbance.

…programs and ending trade can help conserve and …hly threatened or charismatic species.

…educe the damage caused by invasive species is to …ir introduction through trade restrictions or eradicate …y establishment phase.

…e conserved because of the economic value of the …es it provides.

…principles, what are the best spatial configurations …e designs?

…on ecology be used to reestablish the original …ction of degraded ecosystems?

…t ways to reduce the damage caused by …

Figure 57.12

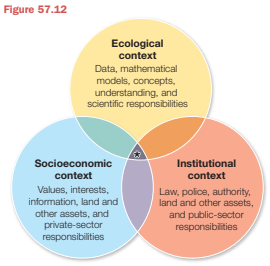
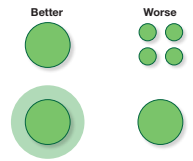


Figure 57.13



> *Life* provides **excellent images to help guide students** through difficult topics."
>
> — Brent Mortenson, Benedictine College

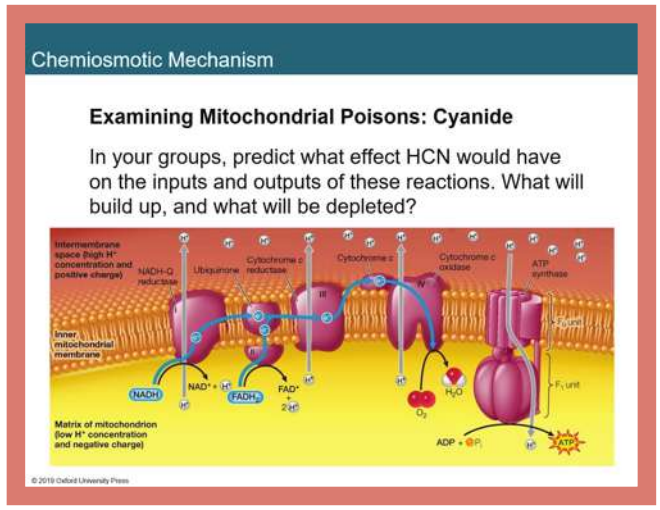
Life The Science of Biology
Focused on Active Learning

Active Learning Modules

The **Active Learning Modules** provide everything an instructor needs to successfully implement an active approach to teaching key topics. Each module includes many resources, including:

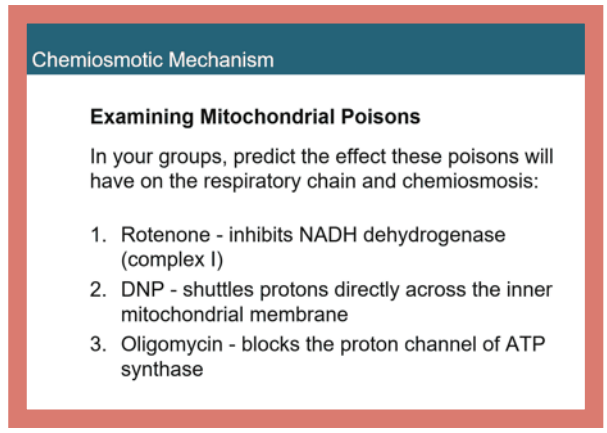
- Pre-class video specifically created for the module
- Pre-quiz and post-quiz
- Handout for in-class work
- Detailed in-class exercise
- Detailed instructor's guide

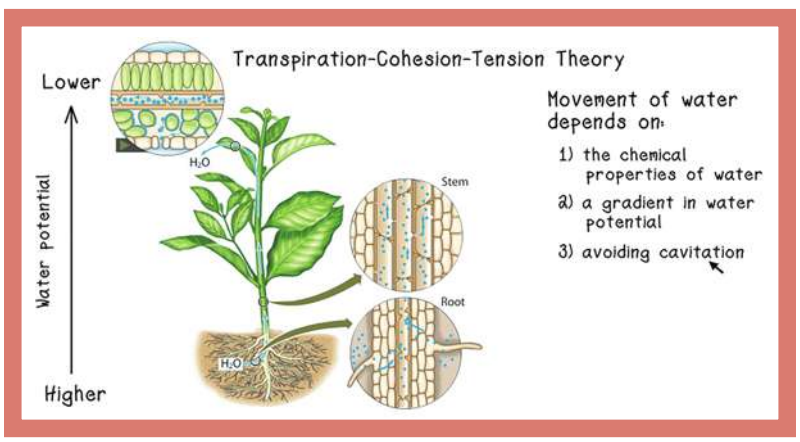
These modules are easy to implement and are a great way to add more active learning to the classroom.



Active Learning Guide

The **Active Learning Guide** provides extensive resources and support for implementing active learning techniques in the classroom. It includes a thorough introduction to the concepts, techniques, and benefits of active learning, along with chapter-by-chapter guidance on teaching using the many active learning resources we provide for *Life.*





Integration with iClicker

Student confidence and end-of-course grades increase with the use of **iClicker**. iClicker includes a geolocation attendance feature to get students to class. During class, instructors can choose from flexible polling and quizzing options to engage students, check understanding, and get feedback in real time. Additionally, iClicker allows students to participate using laptops, mobile devices, or iClicker remotes—all in the same classroom. Instructors can easily sync grades between iClicker and **Achieve** as well as use student response questions specific to *Life*. To learn more or schedule a demo, visit **iClicker.com**.

"I absolutely love the active nature of the built-in Activity sections; they are quick to access from the digital version of the textbook."

—Jason Duncan, Willamette University

Life The Science of Biology
Content Updates

PART 1: The Science of Life and Its Chemical Basis

- Clarification and figure describing valence shell and the periodic table
- Clarification and new figure on representations of bonding
- Definition and more discussion of the importance of pH
- Clearer discussion of phosphodiester bond formation in nucleic acids
- Inclusion of lipoprotein structure and function
- Updates on the search for water on extraterrestrial bodies
- Recent evidence for the origin of cells

PART 2: Cells

- Background on the cell theory
- More extensive discussion of cell size
- Clear differentiation between chromosomes and chromatin in the nucleus
- Roles of the different regions of the Golgi apparatus in the secretory pathway
- Clarification of the roles of kinesin and dynein in movements
- Role of the extracellular matrix in organ formation
- Clarification of the role of integrins in cell attachment to the matrix
- Clearer description of the sodium–potassium ion pump
- Discussion of cross-talk between cell signaling pathways

PART 3: Cells and Energy

- Clearer linkage between free energy changes and biochemical transformations
- Specific examples of activation energy in enzyme-catalyzed reactions
- Additional detail on the structure and role of pyruvate dehydrogenase
- Clarification of the difference between chlorophyll *a* and chlorophyll *b*
- Clearer illustrations and discussion of the structure and function of a photosystem in the chloroplast
- Comparison of C_4 and CAM photosynthesis

PART 4: Genes, Genomes, and Heredity

- Reorganization to the unit so Chapter 17: *Genomes* and Chapter 18: *Recombinant DNA and Biotechnology* are included in Part 4
- Sections dealing with mutations substantially altered to clarify the relationships between DNA damage, DNA mismatches and DNA mutations, and the role of DNA repair
- Update of transcription initiation in eukaryotes to include mediator
- Substantial update of Chapter 17: *Genomes*, including addition of transcriptomics, SNP genotyping, and use of SNPs in ancestry and association studies
- Expansion of Chapter 18: *Recombinant DNA and Biotechnology* to include greater detail on transgenics, cloning, reporters, genetic screens, and other methods to identify genes of interest, and uses of CRISPR

PART 5: The Processes and Patterns of Evolution

- Major expansion and update of Chapter 21: *Evolution of Genes and Genomes*
- Expansion and integration of developmental mechanisms of evolution through changes in gene expression
- More integration of phylogeny and its uses throughout the questions and problem sets
- Addition of more data-based problems so that students can apply evolutionary concepts to practical problems in biology

PART 6: Diversity of Life

- Updated information on our current knowledge of the tree of life
- More discussion of the origins of the major lineages of life, with explanations of the contributions to eukaryotes from both archaea and bacteria
- New problem sets that allow students to explore the basis for our understanding of the tree of life

PART 7: Flowering Plants: Form and Function

- Enhanced emphasis on plants' ability to sense and respond to the environment, including a new figure that shows how roots grow in response to low levels of P and N
- Updated treatment of osmosis that corrects common misconceptions
- Updated description of plant meristems
- Introduced exciting new data showing that the rate of dark reversion of phytochrome may act as a temperature sensor
- Increased focus on plant response to climate change

PART 8: Animals: Form and Function

- New Chapter 38 Investigating Life box on Ebola and emergency workers who face heat stress due to wearing protective gear
- New figure and increased coverage of glia and the glymphatic system
- Updated coverage about birth control methods
- Improved coverage of thyroxin with revised figure showing the steps of biosynthesis of the hormone
- Revised coverage and figures on the evolution of the vertebrate heart
- New figure and more detail on the mechanism of penile erection
- Improved coverage of 3-D vision

PART 9: Ecology

- A consistent focus on the importance of scale and multiple levels of organization in ecology. Special emphasis has been placed on global change and the role of humans as part of Earth's systems
- Inclusion of quantitative and conceptual material in order to visualize (through figures) and analyze (through Work with the Data questions) concepts using active learning techniques
- Updated examples, including marine, invasive species, and endangered species studies
- Updated content on the effects of Earth's topography on physical processes such as temperature inversion, ocean upwelling, and rain shadow effects
- Updated content on population growth models and examples, including material on life table analysis
- Updated content on disturbance and succession including the concept of alternative stable states
- Updated content on nutrient cycling at ecosystem and global scales, including decomposition, nutrient transformations, and the causes of climate change
- Updated content on the causes and consequences of biodiversity loss, including pollution, overharvesting, invasive species, emerging diseases, and the effects of climate change

Life The Science of Biology
Media Updates

Updates to the Media and Assessment Resources

Activities

- A new format for most activities, designed to better engage the student

Simulations

- New simulations on topics such as macromolecules, active and passive transport, and natural selection
- Each simulation is now accompanied by an assignable quiz in **Achieve**.

Animations

- A new video format that incorporates captions directly into the video

Data in Depth

- Each in-book **Work with the Data** exercise has a new online companion exercise, **Data in Depth**, designed to deepen students' data manipulation skills.

Interactive Stats Primer

- The online version of Appendix B, **Making Sense of Data: A Statistics Primer** gives students the opportunity to learn basic statistical concepts and skill through hands-on simulations and activities.

Active Learning Guide and Instructor's Manual

- A thorough primer on active learning in biology
- Includes sections such as:
  - What is active learning?
  - Designing your course for active learning
  - Using active learning in the classroom
  - How to implement *Life* resources
- Chapter-by-chapter ideas, suggestions, and resources
- Now integrated with the Instructor's Manual

Active Learning Modules

- Robust modules designed to provide all the support an instructor needs to teach selected topics in an active learning setting
- Each module includes a detailed instructor's guide, a pre-quiz, a pre-class video, an in-class exercise, a post-quiz, and assessment questions.

Test Bank

- All questions aligned to new Learning Objectives
- Additional questions at higher Bloom's Levels

LearningCurve

- Expanded question banks for each chapter
- Hints added to all questions

> **LearningCurve, in particular, is very helpful to my students.** Many of my students commented on my student evaluation that they found the online resources and LearningCurve assignments very helpful to them."
>
> —Amanda Chau, Blinn College

About the Authors

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.

H. Craig Heller is the Lorry I. Lokey/Business Wire Professor in Biological Sciences and Human Biology at Stanford University. He has taught in the core biology courses at Stanford since 1972 and served as Director of the Program in Human Biology, Chairman of the Biological Sciences Department, and Associate Dean of Research. Dr. Heller is a fellow of the American Association for the Advancement of Science and a recipient of the Walter J. Gores Award for excellence in teaching and the Kenneth Cuthberson Award for Exceptional Service to Stanford University. His research is on the neurobiology of sleep and circadian rhythms, mammalian hibernation, the regulation of body temperature, the physiology of human performance, and the neurobiology of learning. He has done research on a huge variety of animals and physiological problems, including sleeping kangaroo rats, diving seals, hibernating bears, photo-periodic hamsters, and exercising athletes. Dr. Heller has extended his enthusiasm for promoting active learning via the development of a two-year curriculum in human biology for the middle grades through the production of Virtual Labs—interactive computer-based modules to teach physiology.

Sally D. Hacker is a Professor at Oregon State University where she has been a faculty member since 2004. She has taught courses in introductory ecology, community ecology, invasion biology, field ecology, and marine biology. She was awarded the Murray F. Buell Award by the Ecological Society of America and the Young Investigator Prize by the American Society of Naturalists. Dr. Hacker's research explores the structure, function, and services of natural and managed ecosystems under varying contexts of species interactions and global change. She has conducted research with plants and animals in rocky intertidal, salt marsh, seagrass, and coastal dune ecosystems. Her work has most recently focused on the protective role of dune ecosystems in mitigating coastal vulnerability due to climate change. In addition to the textbooks *Life: The Science of Biology* and *Ecology* (Sinauer Associates), she is author or coauthor on numerous articles and book chapters exploring community ecology, species interactions, marine invasions, and ecosystem services important to coastal management. She is particularly interested in promoting active and experiential learning for students interested in ecology and field-immersion experiences.

David W. Hall is 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 subcellular interactions that establish the plant root system.

David Sadava is the Pritzker Family Foundation Professor of Biology, Emeritus, at the Keck Science Center of Claremont McKenna, Pitzer, and Scripps, three of The Claremont Colleges. In addition, he is Adjunct Professor of Cancer Cell Biology at the City of Hope Medical Center. Twice winner of the Huntoon Award for superior teaching, Dr. Sadava has taught courses on introductory biology, biotechnology, biochemistry, cell biology, molecular biology, plant biology, and cancer biology. In addition to *Life: The Science of Biology*, he is the author or coauthor of books on cell biology and on plants, genes, and crop biotechnology. His research has resulted in many papers coauthored with his students, on topics ranging from plant biochemistry to pharmacology of narcotic analgesics to human genetic diseases. For the past 15 years, he has investigated multi-drug resistance in human small-cell lung carcinoma cells with a view to understanding and overcoming this clinical challenge. At the City of Hope, his current work focuses on new anti-cancer agents from plants.

Acknowledgments

Although our names are on the cover, and we take ultimate responsibility for the contents of this book, we relied on many people for help. We have received a multitude of valuable suggestions across the various editions of *Life* from our Advisory Board. These biologists, from institutions large and small, have helped us plan many of the pedagogical innovations for this edition. These colleagues provided exceptional critiques to our proposals, drawing on their vast teaching experiences in diverse learning environments. As our chapters became reality, the thoughtful insights of these advisors were invaluable. In addition, with their varied experiences incorporating online material into their teaching, the members of the Advisory Board were an important source of feedback as we developed the active learning and assessment materials associated with the book. We could not have done it without them.

Many thousands of people have reviewed the chapters of *Life* over its 12 editions, and another 180 reviewers guided us in this revision by providing between-edition reviews and suggestions for each of our chapters. They helped us decide what needed improving and gave us suggestions to make that happen. With our emphasis on active learning and pedagogy, we also asked experts in biology education to critique our pedagogical features and give us suggestions for improvement. We are grateful to each and every one of these reviewers.

The talented team at Sinauer Associates included Sydney Carroll, who provided the editorial oversight for the Twelfth Edition. Dean Scudder managed the Sinauer team and provided guidance and suggestions in the planning and development of *Life*. We also thank our Production Editors, Danna Niedzwiecki Lockwood, Johannah Walkowicz, and Tracy Marton, who edited our chapters, and helped us implement and maintain consistency in our features. We are grateful to Mark Siddall, who located new, fresh photographs to illustrate the chapters; Michele Beckta and Tracy Marton, who managed the permissions process and were ever vigilant in prompting us to track down data sources; Joan Gemme and Donna DiCarlo, who created the design and managed the production of the book's cover and pages; Liz Pierson, who skillfully copyedited all the chapters; and Suzanne Carter, who directed a team of talented media and supplements editors and writers.

We appreciate the ongoing support of John Challice and Petra Recter from Oxford University Press. Macmillan Learning has worked aggressively to bring *Life* to a broader audience. Executive Marketing Manager Will Moore, Executive Program Manager for Biology Lisa Lockwood, and Executive Program Director for Life Sciences Sandy Lindelof, along with the regional specialists, regional managers, and experienced sales force, are effective ambassadors and skillful transmitters of the strong features and unique strengths of this new edition. We depend upon their experience and energy to keep us in touch with how *Life* is perceived by its users.

Finally, we thank Andy Sinauer, who was our publisher for the first 11 editions of *Life*, and who recruited most of us to the author team. Although Andy has now retired, his love of biology, his commitment to education, and his standards of excellence in publishing continue to inspire us all.

DAVID HILLIS
CRAIG HELLER
SALLY HACKER
DAVID HALL
MARTA LASKOWSKI
DAVID SADAVA

Reviewers and Contributors

Between-Edition Reviewers

Danyelle N. Aganovic, University of North Georgia

Cristian Aguilar, Azusa Pacific University

Norma Allewell, University of Maryland, College Park

Christine Andrews, University of Chicago

Jason Arnold, Hopkinsville Community College

Miriam Ashley-Ross, Wake Forest University

Linda Auker, St. Lawrence University

Katherine Barker, Blinn College

Geoffrey Benn, University of California at Davis

Michael Berger, Washington State University

Alex Bezzerides, Lewis-Clark State College

Mary Bisson, University at Buffalo

Kristina Blanke, University at Buffalo

Andrew Blaustein, Oregon State University

Luis Bonachea, University of Pittsburgh at Johnstown

James Bottesch, Eastern Florida State College

Nicole Bournias-Vardiabasis, California State University, San Bernardino

Christopher Brandon, Florida Southern College

Mirjana M. Brockett, Georgia Institute of Technology

Chris Burcher, Virginia Highlands Community College

Stephen Burnett, Clayton State University

Shere Kuss Byrd, Fort Lewis College

Alisha Campbell, Northwest Missouri State University

Billy Carver, Lees-McRae College

Dale Casamatta, University of North Florida

Alyson Center, Normandale Community College

Rebekah Chapman, Georgia State University

Prescott Bryant, Chase Florida State University

Amanda Chau, Blinn College

Charles Chen, Azusa Pacific University

Byung Min Chung, The Catholic University of America

Cynthia Church, Metropolitan State University of Denver

Kari Clifton, University of West Florida

Heather Coan, Western Carolina University

Kelly Collins, Lees-McRae College

Pamela Connerly, Indiana University Southeast

Frank Corotto, University of North Georgia

Christopher M. Cottingham, University of North Alabama

Elizabeth Cowles, Eastern Connecticut State University

David P. Craig, Willamette University

Lorelei Crerar, George Mason University

Jennifer Cymbola, Grand Valley State University

Mary Ellen Czesak, Vassar College

Christine Dahlin, University of Pittsburgh at Johnstown

Candice Damiani, University of Pittsburgh

Douglas Darnowski, Indiana University Southeast

Alyce DeMarais, University of Puget Sound

William Dentler, University of Kansas

Tiffany Doan, New College of Florida

Cathleen Dobbs, Joliet Junior College

Jennifer Doherty, University of Washington

Jason Duncan, Willamette University

Kelli Duncan, Vassar College

Megan Dunn, Indiana University

Ana Esther Escandon, Los Angeles Harbor College

Melinda Faulkner, Bradley University

Kenneth Filchak, University of Notre Dame

Janet Fisher, University of West Georgia

Lee Ann Frederick, University of Texas at Arlington

Pamela Freeman, College of St. Scholastica

Marian M. Furimsky, Westminster College (PA)

Megan D. Gall, Vassar College

Kathryn Gardner, University of Pittsburgh

Renaud Geslain, College of Charleston

Raffaella Ghittoni, University of Southern California

William Gilliland, DePaul University, Chicago

Gwen Goodmanlowe, California State University, Long Beach

Suzanna Gribble, University of Pittsburgh

Eric Haag, University of Maryland, College Park

Gokhan Hacisalihoglu, Florida A&M University

Michael K. Hamed, Virginia Highlands Community College

Donna Hamilton, University of North Texas, Dallas

Phillip Harris, The University of Alabama

Wayne Hatch, Utah State University Eastern

Brian T. Hentschel, San Diego State University

Brad Hersh, Allegheny College

Ayana Hinton, Denison University

Mark A. Holbrook, University of Iowa

William Huddleston, University of Calgary

Victor Izzo, University of Vermont

Jamie Jensen, Brigham Young University

Heather Joesting, Georgia Southern University

Michael Johanson, Blinn College

Gregory Johnson, University of Puget Sound

Jerald B. Johnson, Brigham Young University

Gregory Jones, Santa Fe College

Carly Jordan, The George Washington University

Jennifer Jost, Bradley University

Joshua Kapfer, University of Wisconsin, Whitewater

Lori Kayes, Oregon State University

Moshe Khurgel, Bridgewater College

Henrik Kibak, California State University, Monterey Bay

Kelly C. Kissane, Blinn College–Brenham Campus

Amy Klocko, University of Colorado, Colorado Springs

Ross Koning, Eastern Connecticut State University

Jason Kuehner, Emmanuel College

Stacie Kutz, The Sage Colleges

Kim Lackey, University of Alabama

Adriana LaGier, Grand View University

Diane Lahaise, Georgia State University–Perimeter College

Kari Lavalli, Boston University

Chris Levesque, John Abbott College

Eric Liebl, Denison University

Faith Liebl, Southern Illinois University

Samantha Lin, Yale University

Craig Longtine, North Hennepin Community College

Laura Lorentzen, Kean University

Christopher Loretz, University at Buffalo
Peter Lyons, Andrews University
Elizabeth Machunis-Masuoka, Midwestern State University
Jay Mager, Ohio Northern University
Charles Mallery, University of Miami
Barry J. Margulies, Towson University
Carolyn Martineau, DePaul University
Lori McGrew, Belmont University
Gerard McNeil, York College/City University of New York
Jennifer Metzler, Ball State University
Roderick Morgan, Grand Valley State University
Brent Mortensen, Benedictine College
LaSharon Mosley, University of Cincinnati
Patricia Mote, Georgia State University
Orissa Moulton, Texas A&M University, Galveston
James Murphy, Bloomfield College
Barbara Musolf, Clayton State University
Benjamin Navia, Andrews University
Judy Nesmith, University of Michigan, Dearborn
Jennifer Ness, Bradley University
Robert H. Newman, North Carolina A&T State University
Wade Nichols, Illinois State University
Alexey Nikitin, Grand Valley State University
Eric Norstrom, DePaul University
Matthew Nusnbaum, Georgia State University
Alexander E. Olvido, University of North Georgia
Robert Osuna, University at Albany, State University of New York
Ellen Ott-Reeves, Blinn College
Irvin Pan, Stonehill College
Janet Paper, Benedictine College
Kristin Picardo, St. John Fisher College
Daniel Potter, University of California, Davis
Kimberly Quaranta, Arizona State University
Elizabeth Rielly, Holy Family University
Leslie Riley, Ohio Northern University
Laurel Roberts, University of Pittsburgh
Ben Rowley, University of Central Arkansas
Charlotte Russell, Simmons University
Susan Sadler, University of Denver
Cassandra Saitow, Simmons College
Donald Sakaguchi, Iowa State University
James Reid Schwebach, George Mason University
Erik P. Scully, Towson University
Anupama Shanmuganathan, Washington & Jefferson College
Sylvia Sharp, Saginaw Valley State University
Tonya Shepherd, Blinn College & Texas A&M University
James Shinkle, Trinity University
Erin Shortlidge, Portland State University
Cahleen Shrier, Azusa Pacific University
Bin Shuai, Wichita State University
William K. Smith, Wake Forest University
Robert Steven, University of Toledo
Michaela Gazdik Stofer, Utah Valley University
Fengjie Sun, Georgia Gwinnett College
Cynthia A. Surmacz, Bloomsburg University of Pennsylvania
Ken Gunter Sweat, Arizona State University
Zuzana Swigonova, University of Pittsburgh
Edward Tall, Seton Hall University
Rebekah Taylor, Frostburg State University
Ilya Temkin, Northern Virginia Community College
Jennifer T. Thomas, Belmont University
Beverly Thompson, Tri-County Technical College
Monica S. Torres, Rutgers University
Catherine Trivigno, Florida Atlantic University
Cynthia van Golen, Delaware State University
Doug Van Hoewyk, Coastal Carolina University
Matthew Venesky, Allegheny College
Brian G. Walker, Fairfield University
Lisa B. Whitenack, Allegheny College
Cathy Whiting, University of North Georgia
Larry Wimmers, Towson University
Steven Wood, Blinn College
Robert Zdor, Andrews University

Media and Supplements Contributors

Moira Conith, University of Massachusetts, Amherst
Jill DeVito, University of Texas, Arlington
Donna Francis, University of Massachusetts, Amherst
Richard Gill, Brigham Young University
Carol Hand, Science writer
Phillip Harris, University of Alabama
Margaret Hill, Science writer
Kendra Hutchins, Cornell University
Norman Johnson, University of Massachusetts, Amherst
Carly Jordan, The George Washington University
Laurie Leonelli, New York University
Betty Anne McGuire, Cornell University
Meredith Safford, Johns Hopkins University
John Townsend-Mehler, Montana State University
Mary Tyler, University of Maine, Orono
Robert Wise, University of Wisconsin, Oshkosh (emeritus)

Media and Supplements

to accompany *Life: The Science of Biology*, Twelfth Edition

Achieve is the easy-to-use online platform that integrates the e-book, all of the student and instructor media resources, and assessment functions into one clean, unified interface. For more about **Achieve**, see pages viii–xiii and visit macmillanlearning.com/Achieve.

Student Resources

ACTIVITIES. A range of interactive activities helps students learn and review key facts and concepts through labeling diagrams and identifying structures and stages of processes.

SIMULATIONS. Dynamic simulations allow students to explore how biological systems and processes work. Each is accompanied by a brief quiz.

ANIMATIONS. In-depth animations present complex topics in a clear, easy-to-follow format. Each is accompanied by a brief quiz.

MEDIA CLIPS. These engaging video clips depict fascinating examples of some of the many organisms, processes, and phenomena discussed in the textbook.

DATA IN DEPTH. These online companions to the in-text Work with the Data exercises help students improve data literacy and quantitative skills through interactive exercises and questions.

LEARNINGCURVE. A powerful adaptive quizzing system with a game-like format that engages students. See page xv for details.

SUMMATIVE QUIZZES. Pre-built quizzes that assess overall student understanding of each chapter.

APPLY WHAT YOU'VE LEARNED. Exercises that challenge students to put their knowledge into action by answering questions related to specific research findings.

VIDEOS. The wide-ranging collection of video segments helps demonstrate the complexity and beauty of life.

TREE OF LIFE. An interactive version of the tree of life from Appendix A, with links to a wealth of information on each group listed.

BIONEWS FROM *SCIENTIFIC AMERICAN*. BioNews makes it easy for instructors to bring the dynamic nature of the biological sciences and up-to-the-minute currency into their course via an automatically updated news feed in **Achieve**.

Instructor Resources

TEXTBOOK FIGURES AND TABLES. Every figure and table from the textbook (including all photos and all unnumbered figures) is provided in both JPEG and PowerPoint formats, in multiple versions, including whole, reformatted, and unlabeled.

POWERPOINT RESOURCES. For each chapter of the textbook, several different PowerPoint presentations are available, providing instructors the flexibility to build presentations in the manner that best suits their needs:

- Textbook Figures and Tables
- Lecture Presentations
- Layered Art Figures
- Active Learning Module In-Class Exercises

ACTIVE LEARNING GUIDE & INSTRUCTOR'S MANUAL. This guide provides an excellent overview of active learning techniques for introductory biology, along with chapter-specific support. Active learning resources and suggestions are all organized by Key Concept, with Learning Objectives included. Also included are the following sections for each chapter: *Chapter Overview*, *What's New in This Edition*, *Chapter Outline*, and *Key Terms*. See page xiii for details.

ACTIVE LEARNING MODULES. These comprehensive modules provide instructors everything they need to teach selected key topics using an active learning approach. See page xiii for details.

ANSWERS TO TEXTBOOK QUESTIONS. Answers to all of the in-text questions: Recap and Assess questions, Work with the Data questions, Figure questions, and Visual Summary questions.

ANSWERS TO APPLY WHAT YOU'VE LEARNED. Answers to all of the Apply What You've Learned exercises.

TEST BANK. The *Life* Test Bank includes over 7,000 questions, all referenced to specific Key Concepts, Learning Objectives, and Bloom's Levels. Each chapter includes a wide range of multiple-choice and short-answer questions.

COMPUTERIZED TEST BANK. The Test Bank is also available in Cognero format, with software included, for easy exam and quiz creation.

LEARNING MANAGEMENT SYSTEM SUPPORT. Easy LMS integration into any school's learning management system—such as Blackboard, Canvas, D2L/Brightspace, Moodle, and more—means your gradebook and roster are always in sync and your students also get the benefit of single sign-on.

Additional Resources

iClicker

Instructors, get more out of your classroom.
iClicker's innovative solutions make it easy to track attendance, increase participation, facilitate quizzes, measure performance, and get more out of your classroom. For more information, visit **iclicker.com**.

LabPartner

Macmillan Learning Lab Solutions
Macmillan Learning Lab Solutions unites the same brands you know and trust—W. H. Freeman, Hayden-McNeil, Sapling Learning, and Late Nite Labs—and provides the resources to build a seamless, comprehensive lab experience for your students. For more information, visit **macmillanlearning.com/LabSolutions**.

CatchUp Math & Stats for the Life Sciences
Michael Harris, Gordon Taylor, and Jacquelyn Taylor
(ISBN 978-1-4292-0557-3)
Presented in brief, accessible units, this primer will help students quickly brush up on the quantitative skills they need to succeed in biology.

***A Student Handbook for Writing in Biology,* Fifth Edition**
Karin Knisely (ISBN 978-1-3191-2181-5)
This book provides practical advice to students who are learning to write according to the conventions in biology, using the standards of journal publication as a model.

BioStats Basics: A Student Handbook
James L. Gould and Grant F. Gould (ISBN 978-0-7167-3416-1)
Engaging and informal, *BioStats Basics* provides introductory-level biology students with a practical, accessible introduction to statistical methodology.

Hayden-McNeil Life Sciences Lab Notebook
(ISBN 978-1-4292-3055-1)
This durable, high-quality carbonless laboratory notebook allows students to hand in originals or copies of their lab work, not entire composition books. The Lab Notebook contains Hayden-McNeil's unique white paper carbonless copies and biology-specific reference materials.

W.H. FREEMAN SCIENTIFIC TEACHING

The *Scientific Teaching* Book Series
The Series is a collection of practical guides, intended for all science, technology, engineering and mathematics (STEM) faculty who teach undergraduate and graduate students in these disciplines. The purpose of these books is to help faculty become more successful in all aspects of teaching and learning science, including classroom instruction, mentoring students, and professional development. Authored by well-known science educators, the Series provides concise descriptions of best practices and how to implement them in the classroom, the laboratory, or the department. For readers interested in the research results on which these best practices are based, the books also provide a gateway to the key educational literature. The Series includes:

Scientific Teaching
Jo Handelsman, Sarah Miller, and Christine Pfund
(ISBN 978-1-4292-0188-9)

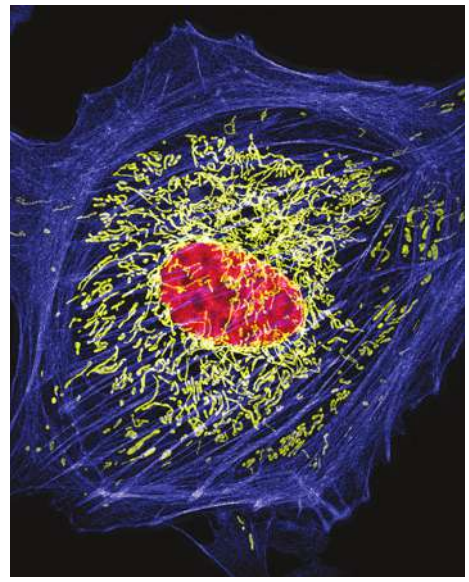
Transformations: Approaches to College Science Teaching
Deborah Allen and Kimberly Tanner
(ISBN 978-1-4292-5335-2)

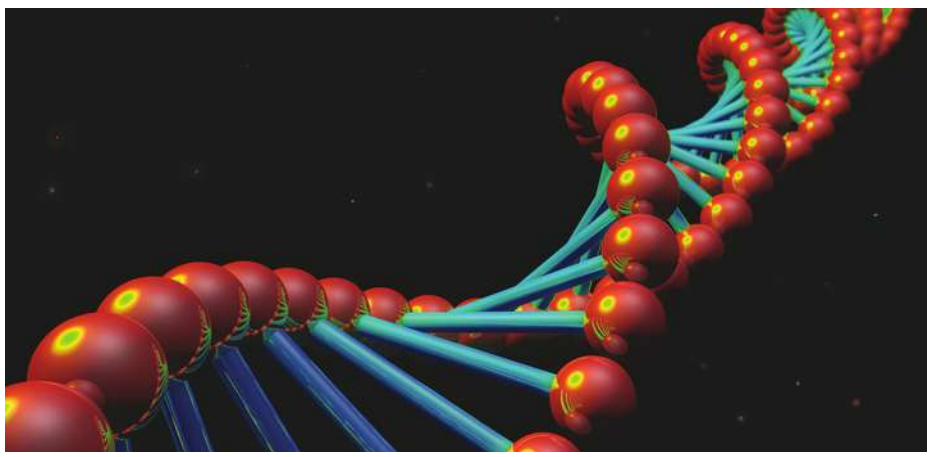
***Entering Research: A Curriculum to Support Undergraduate & Graduate Research Trainees*, Second Edition**
Janet L. Branchaw, Amanda R. Butz, and Amber Smith
(ISBN: 978-1-3192-6368-3)

Discipline-Based Science Education Research: A Scientist's Guide
Stephanie J. Slater, Timothy F. Slater, and Janelle M. Bailey
(ISBN 978-1-4292-6586-7)

Assessment in the College Classroom
Clarissa Dirks, Mary Pat Wenderoth, and Michelle Withers
(ISBN 978-1-4292-8197-3)

Contents






© Michael Ventura/Alamy Stock Photo

© imageBROKER/Alamy Stock Photo