Evolution and Medicine

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Please contact the NIH Office of Science Education with questions about this supplement at supplements@science.education.nih.gov.

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Foreword

Evolution and Medicine is the most recent addition to the National Institutes of Health (NIH) Curriculum Supplement Series. This series brings the latest medical science and research discoveries from NIH into the K–12 classroom. NIH plays a vital role in the health of all Americans and seeks to foster interest in research, science, and medicine-related careers for future generations. The NIH Office of Science Education is dedicated to promoting scientific literacy and the knowledge and skills we need to secure a healthy future for all.

Evolution and Medicine gives students an opportunity to grapple with some of the most challenging and engaging medical issues that confront our society. We designed *Evolution and Medicine* to complement existing life science curricula and to be consistent with *National Science Education Standards*. High school science teachers, medical experts, education specialists, scientists, representatives from NIH, and curriculum-design experts from Biological Sciences Curriculum Study (BSCS) created the activities. The collaborative development process includes geographically dispersed field tests by teachers and students.

The curriculum supplements enable teachers to facilitate learning and stimulate student interest by applying scientific concepts to real-life scenarios. Design elements emphasize key biology concepts and analytic methods, cutting-edge science content, and built-in assessment tools. Activities promote active and collaborative learning to help students develop problem-solving strategies and critical-thinking skills.

Each of our curriculum supplements comes with a complete set of printed materials for teachers, including extensive background and resource information, detailed lesson plans, and masters for student worksheets. The Web site accompanying *Evolution and Medicine* has interactive materials to support the lessons.

The supplements are distributed free to educators across the United States upon request. They may be copied for classroom use and educational purposes but may not be sold.

We welcome your comments. For a complete list of curriculum supplements and ordering information, or to submit feedback, visit http://science.education.nih.gov or write to

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We appreciate the valuable contributions from the talented staff at BSCS. We are also grateful to the NIH scientists, advisors, and all other participating professionals for their work and dedication. Finally, we thank the teachers and students who participated in focus groups and field tests to ensure that these supplements are both engaging and effective. I hope you find our series a valuable addition to your classroom, and I wish you a productive school year.

Bruce A. Fuchs, Ph.D.
Director
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About the National Institutes of Health

Founded in 1887, NIH is the Federal focal point for health research in the United States. Today, it is one of the agencies in the Department of Health and Human Services. Its mission is science in pursuit of fundamental knowledge about the nature and behavior of living systems and the application of that knowledge to extend healthy life and reduce the burdens of illness and disability. NIH works toward meeting the mission by providing leadership, direction, and grant support to programs designed to improve the health of the nation through research.

NIH's education programs contribute to ensuring the continued supply of well-trained basic research and clinical investigators, as well as the myriad professionals in many allied disciplines who support the research enterprise. These efforts also help educate people about scientific results so that they can make informed decisions about their own—and the public's—health.

This curriculum supplement is one such education effort. It is a collaboration between NIH and Biological Sciences Curriculum Study.

For more about NIH, visit http://www.nih.gov.

About Biological Sciences Curriculum Study

Headquartered in Colorado Springs, Colorado, BSCS was founded in 1958 as a curriculum study committed to an evidence- and inquiry-based approach to science education. BSCS instructional materials and professional development services are based on current research about teaching and learning for all science classrooms, kindergarten through college.

BSCS's materials are extensively field-tested in diverse settings across the country and evaluated for proven effectiveness. The BSCS 5E Instructional Model and inquiry are hallmarks of its materials, placing students at the center of their learning.

The BSCS mission is to transform science teaching and learning through research and development that strengthens learning environments and inspires a global community of scientifically literate citizens. BSCS is a 501(c)(3) nonprofit organization. For more information, please visit http://www.bscs.org.

Introduction to *Evolution and Medicine*

There is no question that **evolution** is the major unifying concept in biology and that "nothing in biology makes sense except in the light of evolution" (Dobzhansky, 1973). The teaching and learning of evolution, however, remains a difficult challenge. High school students need invigorating experiences that help them develop a rich understanding of evolutionary principles, and these experiences need to show the relevance of evolution to everyday life. These experiences must also be thoroughly grounded in learning about the nature of science. The *Evolution and Medicine* curriculum supplement incorporates research-based pedagogical approaches to support teachers as they help students understand the fundamental concepts of this dynamic and exciting field of science.

The questions that evolutionary biologists ask overlap with many that medical researchers ask about human health. The burgeoning field of evolution and medicine uses the models and theory of evolutionary biology to inform medical and public health problems. Though insights from evolution can provide immediate assistance in some clinical situations, the leaders in the field suggest that evolution's greatest benefits will be to provide a theoretical framework for understanding

- why organisms are vulnerable to disease,
- how infectious agents evolve, and
- how common ancestry helps scientists use the results from animal models to understand issues related to human health.

Two primary types of questions shape the field: questions about evolutionary processes, such as natural selection, and questions about evolutionary history, or the patterns of evolution. Students investigate case studies that help them develop explanations of medical situations that involve evolutionary processes and patterns.

What Are the Objectives of the Supplement?

Evolution and Medicine has four main objectives: to help students in grades 9–12 understand

1. the importance of evolutionary comparisons for studying biomedical problems;
2. the role of evolution in diseases, including how evolution explains many aspects of humans' susceptibility to disease and how the principles of natural selection apply to specific diseases or health-related conditions;
3. how evolution helps researchers and health workers better understand, prevent, and treat infectious diseases; and
4. the process of scientific inquiry through studying evolution and medicine.

The lessons help students sharpen their skills in observation, critical thinking, experimental design, and data analysis. They also make connections to other disciplines such as English, mathematics, and social science.

As the supplement achieves its objectives, it helps convey to students the purpose of scientific research. Students experience how science provides evidence that we can use to understand and treat human disease. Ongoing research affects how we understand the world around us and gives us the foundation for improving choices about our personal health and the health of our community.

Table 1. Correlation of *Evolution and Medicine* to High School Biology Topics

Topics	Lesson 1	Lesson 2	Lesson 3	Lesson 4	Lesson 5
Populations evolve over time.	✓	✓	✓	✓	✓
Natural selection is a powerful mechanism of evolution.	✓	✓	✓	✓	✓
Analyses of genetic sequences provide an important line of evidence for evolution.	✓	✓	✓	✓	✓
All living things on Earth are related by descent from common ancestors.	✓	✓	✓	✓	✓
The instructions for specifying the characteristics of an organism are carried in DNA, a large polymer formed from four subunits (A, G, C, and T).	✓	✓	✓	✓	✓
The genetic information that underlies heredity is encoded in genes.	✓	✓	✓	✓	✓
Changes in DNA (mutations) occur spontaneously at low rates. Some of these changes make no difference to the organism, whereas others can change cells and organisms.	✓	✓	✓	✓	✓
Complex multicellular organisms are formed as a highly organized arrangement of differentiated cells. This differentiation is regulated through the expression of different genes.	✓		✓		✓

Why Teach the Supplement?

High school life science classes offer an ideal setting for integrating many areas of student interest. In this supplement, students participate in activities that integrate inquiry, science, human health, mathematics, and science-technology-society relationships. The real-life context of the supplement's classroom lessons is engaging for students, and they can immediately apply what they learn to their lives.

What's in It for the Teacher?

Evolution and Medicine meets many of the needs of teachers in modern classrooms:

- The supplement meets science content, teaching, and assessment standards in the *National Science Education Standards*. It pays particular attention to the standards on **scientific inquiry**.
- It is **integrated** with other subjects, drawing most heavily from science, social science, mathematics, and health.
- It has a Web-based **technology component** that includes interactive activities, tutorials, and simulations.

In addition, the supplement provides a means for **professional development**. Teachers can engage in new and different teaching practices like those described in this supplement without completely overhauling their entire program. In *Designing Professional Development for Teachers of Science and Mathematics*, S. Loucks-Horsley and coauthors (1998) write that supplements such as *Evolution and Medicine* can "offer a window through which teachers can get a glimpse of what new teaching strategies look like in action." By experiencing a short-term supplement like this one, teachers can "change how they think about teaching and embrace new approaches that stimulate students to problem solve, reason, investigate, and construct their own meaning for the content." The use of supplemental material like *Evolution and Medicine* can encourage reflection and discussion and stimulate teachers to improve their practices by focusing on student learning through inquiry.

A correlation of the supplement's major concepts with the biology and scientific inquiry topics often included in the high school life science curricula is shown in Tables 1 and 2. We hope this information will help teachers make decisions about incorporating this material into the curriculum.

Table 2. Correlation of *Evolution and Medicine* to High School Scientific Inquiry Topics

Topics	Lesson 1	Lesson 2	Lesson 3	Lesson 4	Lesson 5
Design and conduct scientific investigations.		✓	✓	✓	
Use technology and mathematics to improve investigations and communications.		✓	✓	✓	
Formulate and revise scientific explanations and models using logic and evidence.	✓	✓	✓	✓	✓
Recognize and analyze alternative explanations and models.		✓	✓	✓	✓

Implementing the Supplement

We designed the five lessons in this supplement to be taught in sequence for approximately 10 days, assuming class periods of about 50 minutes. The following pages offer general suggestions about using these materials in the classroom; you will find specific suggestions in the procedures of each lesson.

What Are the Goals of the Supplement?

Evolution and Medicine is designed to help students attain these major goals associated with scientific literacy:

- to understand a set of basic scientific principles related to evolution and how evolution relates to medicine,
- to experience the process of scientific inquiry and develop an enhanced understanding of the nature and methods of science, and
- to recognize the role of science in society and the relationship between basic research and human health.

What Are the Science Concepts and How Are They Connected?

The lessons are organized into a conceptual framework that allows students to start with what they already know about evolution, some of which may be incorrect. They then move to a scientific perspective on evolution and its importance to medicine and to their lives.

In Lesson 1, students begin by considering their initial thoughts about how methicillin-resistant *Staphylococcus aureus*, or MRSA, evolved antibiotic resistance. They next consider their ideas about how common ancestry helps explain the use of model systems for medical research. Students then explore the frequency of lactase persistence in different groups of people around the world and compare two alternative hypotheses for the evolution of this trait (Lesson 2). By conducting two case studies in Lesson 3, students explain how studies of both evolutionary processes (such as natural selection) and evolutionary patterns (such as changes in genetic sequences) inform medicine. In Lesson 4, students use what they learned about evolution and how it affects medicine to better understand influenza. The main question that drives the lesson is, Why is a new flu vaccine needed every few years?

Lesson 5, the final lesson, gives students an opportunity to consider what they have learned in the previous lessons. Students review an article that a fictional student prepared for the school newspaper about how humans and other species lack the ability to synthesize vitamin C. The task is to identify—and then correct—errors in the article. The lesson concludes with students writing a summary of how evolution informs medicine. The following chart (Table 3) illustrates the science content and conceptual flow of the lessons.

Table 3. Science Content and Conceptual Flow of the Lessons

Lesson	Learning Focus, from BSCS 5E Instructional Model	Major Concepts
Lesson 1—Ideas about the Role of Evolution in Medicine	Engage	Understanding mechanisms of evolution, particularly adaptation by natural selection, provides many insights that enhance medical practice and understanding. Common ancestry explains why experiments in model systems inform human health. Students may have naïve preconceptions about how organisms change over time and about common ancestry.
Lesson 2—Investigating Lactose Intolerance and Evolution	Explore	Some of the variation among humans that may affect health is distributed geographically. Natural selection helps explain some of these patterns. Scientists use data to evaluate evidence for claims about evolution.
Lesson 3—Evolutionary Processes and Patterns Inform Medicine	Explain	Human health and disease are related to our evolutionary history. Understanding evolution helps explain why some diseases are more common in certain parts of the world. Common ancestry explains why information about other organisms is useful for studying health-related issues in humans. Rates of evolutionary change in genetic sequences give clues about the role of natural selection on that genetic region. Scientists use data to evaluate evidence for claims about evolution.
Lesson 4—Using Evolution to Understand Influenza	Elaborate	We can compare genetic sequences; the rates of evolutionary change in them give clues about the role of natural selection in that genetic region, which informs medical scientists. Understanding evolution helps explain the emergence and spread of infectious diseases. Scientists use data to evaluate evidence for claims about evolution.
Lesson 5—Evaluating Evolutionary Explanations	Evaluate	Interpreting examples of evolution and medicine requires careful attention to evidence. Natural selection and common ancestry help explain why humans are susceptible to many diseases.

How Does the Supplement Correlate to the *National Science Education Standards*?

Evolution and Medicine supports teachers in their efforts to reform science education in the spirit of the National Research Council's 1996 *National Science Education Standards* (*NSES*). The content of the supplement is explicitly standards based. The following chart (Table 4) lists the specific content standards that this supplement addresses.

Table 4. Alignment of *Evolution and Medicine* Lessons with National Science Education Standards for Content, Grades 9–12

Table 4a. NSES Standard A, Science as Inquiry

As a result of activities in grades 9–12, all students should develop	Correlation to *Evolution and Medicine* Lessons
Abilities necessary to do scientific inquiry	All
• Identify questions and concepts that guide scientific investigations.	1, 2, 3, 4
• Design and conduct scientific investigations.	2, 3, 4
• Use technology and mathematics to improve investigations and communications.	2, 3, 4
• Formulate and revise scientific explanations and models using logic and evidence.	All
• Recognize and analyze alternative explanations and models.	2, 3, 5
• Communicate and defend a scientific argument.	2, 3, 4, 5
Understandings about scientific inquiry	All
• Scientists usually inquire about how physical, living, or designed systems function. Conceptual principles and knowledge guide scientific inquiries. Historical and current scientific knowledge influence the design and interpretation of investigations and the evaluation of proposed explanations made by other scientists.	All
• Scientists conduct investigations for a wide variety of reasons. For example, they may wish to discover new aspects of the natural world, explain recently observed phenomena, or test the conclusions of prior investigations or the predictions of current theories.	2, 3, 4, 5
• Scientists rely on technology to enhance the gathering and manipulation of data. New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science. The accuracy and precision of the data, and therefore the quality of the exploration, depends on the technology used.	3, 4
• Mathematics is essential in scientific inquiry. Mathematical tools and models guide and improve the posing of questions, gathering data, constructing explanations and communicating results.	3, 4
• Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modification; and it must be based on historical and current scientific knowledge.	2, 3, 4, 5
• Results of scientific inquiry—new knowledge and methods—emerge from different types of investigations and public communication among scientists. In communicating and defending the results of scientific inquiry, arguments must be logical and demonstrate connections between natural phenomena, investigations, and the historical body of scientific knowledge. In addition, the methods and procedures that scientists used to obtain evidence must be clearly reported to enhance opportunities for further investigation.	2, 3, 4, 5

Table 4b. NSES Standards C and F, Life Science and Science in Personal and Social Perspectives

As a result of activities in grades 9–12, all students should develop understanding of	**Correlation to *Evolution and Medicine* Lessons**
Standard C. Biological Evolution	All
• Species evolve over time. Evolution is the consequence of the interactions of (1) the potential for a species to increase its numbers, (2) the genetic variability of offspring due to mutation and recombination of genes, (3) a finite supply of the resources required for life, and (4) the ensuing selection by the environment of those offspring better able to survive and leave offspring.	All
• Natural selection and its evolutionary consequences provide a scientific explanation for the fossil record of ancient life forms, as well as for the striking molecular similarities observed among the diverse species of living organisms.	2, 3, 4, 5
• The millions of different species of plants, animals, and microorganisms that live on earth today are related by descent from common ancestors.	All
Standard C. The Molecular Basis of Heredity	2, 3, 4, 5
• In all organisms, the instructions for specifying the characteristics of the organism are carried in DNA, a large polymer formed from subunits of four kinds (A, G, C, and T). The chemical and structural properties of DNA explain how the genetic information that underlies heredity is both encoded in genes (as a string of molecular "letters") and replicated (by a templating mechanism). Each DNA molecule in a cell forms a single chromosome.	2, 3, 4, 5
• Changes in DNA (mutations) occur spontaneously at low rates. Some of these changes make no difference to the organism, whereas others can change cells and organisms. Only mutations in germ cells can create the variation that changes an organism's offspring.	2, 3, 4, 5
Standard C. The Cell	1, 2, 3, 5
Cells can differentiate, and complex multicellular organisms are formed as a highly organized arrangement of differentiated cells. In the development of these multicellular organisms, the progeny from a single cell form an embryo in which the cells multiply and differentiate to form the many specialized cells, tissues and organs that comprise the final organism. This differentiation is regulated through the expression of different genes.	1, 2, 3, 5
Standard F. Personal and Community Health	2, 3, 4, 5
The severity of disease symptoms is dependent on many factors, such as human resistance and the virulence of the disease-producing organism. Many diseases can be prevented, controlled, or cured. Some diseases, such as cancer, result from specific body dysfunctions and cannot be transmitted.	2, 3, 4, 5

Teaching Standards

The suggested classroom strategies in all the lessons support educators as they work to meet the teaching standards outlined in the *National Science Education Standards* (National Research Council (NRC), 1996). The supplement helps science teachers plan an inquiry-based program by providing short-term objectives for students. It also includes planning tools such as the Science Content and Conceptual Flow of the Lessons chart (Table 3) and a suggested timeline for teaching the supplement (page 18). Teachers can use the supplement to update their curriculum in response to their students' interest in this topic. The focus on active, collaborative, and inquiry-based learning helps teachers support the development of student understandings and nurture a community of science learners.

The structure of the lessons enables teachers to guide and facilitate learning. All the activities encourage and support student inquiry, promote discourse among students, and challenge students to accept and share responsibility for their learning. Using the BSCS 5E Instructional Model, combined with active, collaborative learning, allows teachers to respond effectively to the diversity of student backgrounds and learning styles. The supplement is fully annotated, with suggestions for how teachers can encourage and model the skills of scientific inquiry, as well as foster the curiosity, skepticism, and openness to new ideas and data that characterize the successful study of science.

Assessment Standards

Teachers can engage in ongoing assessment of their teaching and of student learning by using the assessment components embedded in each lesson. The assessment tasks are authentic; they are similar in form to tasks that students will engage in outside the classroom or that scientists do. Annotations guide teachers to these opportunities for assessment and provide answers to questions that can help teachers analyze students' feedback. The assessments include one or more of the following strategies:

- performance-based activities, such as developing graphs or participating in a discussion of health effects or social policies;
- oral presentations to the class, such as reporting experimental results; and
- written assignments, such as answering questions or writing about demonstrations.

How Does the BSCS 5E Instructional Model Promote Active, Collaborative, Inquiry-Based Learning?

The lessons in this supplement use a research-based pedagogical approach called the BSCS 5E Instructional Model, or the BSCS 5Es. The BSCS 5Es are based on a **constructivist** theory of learning. A key premise of this theory is that students are active thinkers who build (or construct) their own understanding of concepts out of interactions with phenomena, the environment, and other individuals. A constructivist view of science learning recognizes that students need time to

- express their current thinking;
- interact with objects, organisms, substances, and equipment to develop a range of experiences on which to base their thinking;
- reflect on their thinking by writing and expressing themselves and comparing what they think with what others think; and
- make connections between their learning experiences and the real world.

The three key findings related to student learning identified in *How People Learn* (Bransford et al., 2000), a comprehensive review of research on learning, support the pedagogical strategies promoted by implementing the BSCS 5Es:

- Students enter class with a variety of preconceptions that may later significantly interfere with learning if those preconceptions are not engaged and addressed.
- To develop competence in a given subject, students must build a strong foundation of

factual knowledge within the context of a coherent conceptual framework.
- Students benefit from a metacognitive approach to learning that emphasizes goal setting and self-monitoring.

The BSCS 5Es sequence the learning experiences so that students can construct their own understanding of a science concept over time. The model leads students through five phases of active learning that are easily described using words that begin with the letter *E*: Engage, Explore, Explain, Elaborate, and Evaluate. Rather than just listening and reading, students are also analyzing and evaluating evidence, experiencing, and talking with their peers in ways that promote the development and understanding of key science concepts. These inquiry-based experiences include both direct experimentation and development of explanations through critical and logical thinking. Students often use technology to gather evidence, and mathematics to develop models or explanations.

The BSCS 5Es emphasize student-centered teaching practices. Students participate in their learning in ways that are different from those seen in a traditional classroom. Tables 5 and 6 exemplify what teachers do and what students do in the BSCS 5E Instructional Model.

The following paragraphs illustrate how we implemented the BSCS 5Es in *Evolution and Medicine*.

Engage

Students come to learning situations with prior knowledge. The Engage lesson gives you the chance to find out what students think about evolution.

The Engage phase of this supplement (in Lesson 1) is designed to
- pique students' curiosity and generate interest in natural selection and common ancestry;
- determine students' current understandings about natural selection and common ancestry;
- encourage students to compare their own thinking about natural selection and common ancestry with that of others; and
- give you a chance to hear or read about students' current conceptions of natural selection and common ancestry, which you can address in the later lessons.

Explore

In the Explore phase of the supplement (Lesson 2), we challenge students to make sense of patterns of lactase persistence around the world. Using an interactive map that shows lactase persistence in Africa, Asia, and Europe, students explore patterns of different variables. They then use actual data from scientific research to compare two alternative hypotheses for the evolution of lactase persistence. Students will reflect and improve on their preliminary explanations after further experiences in Lesson 3. Lesson 2 allows students to express their developing understandings of evolution and medicine through analyzing and comparing data, analyzing alternative explanations, and answering questions.

Explain

The Explain phase provides opportunities for students to connect their previous experiences and formulate explanations about case studies that deal with natural selection and common ancestry. It also allows you to introduce formal language, scientific terms, and content information that might make students' previous experiences easier to describe and explain.

In the Explain phase (Lesson 3), students participate in two case studies. In the first one, they diagnose patients with a mystery disease and then develop an explanation, based on natural selection, for the frequency of the disease in certain parts of the world. In the second case study, students develop an explanation for the conservation of genetic sequences across different organisms by using a combination of natural selection and common ancestry. Students
- explain, in their own words, concepts and ideas about evolution and medicine;
- listen to and compare others' explanations of the results with their own;

Table 5. Understanding the BSCS 5E Instructional Model: What the Teacher Does

Phase	*Consistent* with the BSCS 5E Instructional Model	*Inconsistent* with the BSCS 5E Instructional Model
Engage	• Piques students' curiosity and generates interest • Determines students' current understanding (prior knowledge) of a concept or idea • Invites students to express what they think • Invites students to raise their own questions	• Introduces vocabulary • Explains concepts • Provides definitions and answers • Provides closure • Discourages students' ideas and questions
Explore	• Encourages student-to-student interaction • Observes and listens to the students as they interact • Asks probing questions to help students make sense of their experiences • Provides time for students to puzzle through problems	• Provides answers • Proceeds too rapidly for students to make sense of their experiences • Provides closure • Tells the students that they are wrong • Gives information and facts that solve the problem • Leads the students step-by-step to a solution
Explain	• Encourages students to use their common experiences and data from the Engage and Explore lessons to develop explanations • Asks questions that help students express understanding and explanations • Requests justification (evidence) for students' explanations • Provides time for students to compare their ideas with those of others and perhaps to revise their thinking • Introduces terminology and alternative explanations after students express their ideas	• Neglects to solicit students' explanations • Ignores data and information students gathered from previous lessons • Dismisses students' ideas • Accepts explanations that are not supported by evidence • Introduces unrelated concepts or skills
Elaborate	• Focuses students' attention on conceptual connections between new and previous experiences • Encourages students to use what they have learned to explain a new event or idea • Reinforces students' use of scientific terms and descriptions previously introduced • Asks questions that help students draw reasonable conclusions from evidence and data	• Neglects to help students connect new and former experiences • Provides definitive answers • Tells students that they are wrong • Leads students step-by-step to a solution
Evaluate	• Observes and records as students demonstrate their understanding of concept(s) and performance of skills • Provides time for students to compare their ideas with those of others and perhaps to revise their thinking • Interviews students as a means of assessing their developing understanding • Encourages students to assess their own progress	• Tests vocabulary words, terms, and isolated facts • Introduces new ideas or concepts • Creates ambiguity • Promotes open-ended discussion unrelated to the concept or skill