EVO TEACHERS GUIDE: TEN QUESTIONS EVERYONE SHOULD ASK ABOUT EVOLUTION

Rodger W. Bybee and John Feldman

NSTApress
National Science Teachers Association

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PREFACE

This teachers guide for the DVD *EVO: Ten Questions Everyone Should Ask About Evolution* is for science teachers with the dedication, interest, and courage to introduce a unique approach to teaching biological evolution. During the development of *EVO*, we recognized the necessity for a teachers guide that would provide science teachers with insights and support as they implemented an integrated approach to instruction.

This teachers guide provides (1) an introduction to the scientists who are interviewed in *EVO*, (2) background on the 10 questions that form the structure of *EVO*, (3) different ways *EVO* can be implemented, (4) examples of teaching that incorporate the DVD and interviews from *EVO*, and, finally, (5) references and resources for those teachers with the interest and motivation to extend the study of biological evolution.

This project represents collaboration between a filmmaker and a science educator, both interested in biological evolution. The following are brief personal statements from John Feldman, the filmmaker, and then Rodger Bybee, the science educator (curriculum developer).

FROM THE FILMMAKER

When I traveled to the Galápagos Islands in 2005 to lead a workshop making a film about the World Summit on Evolution, little did I know that I would spend the next five years studying evolution and the ways that film can assist in teaching science. My partners, mentors, and the scientists we interviewed at the Summit, as well as other generous and experienced science teachers, educators, students, and members of the scientific community have been incredibly insightful and expressive throughout this journey.

I take the charge of educating through film seriously. This film is based on respect for science and the way that science matters in providing us with a way to respond intelligently, effectively, and ethically to our responsibilities as citizens of the Earth.

Every day's breaking news brings more evidence that we cannot afford to be ignorant about evolution. The study of evolution encourages a deep awareness of the interdependence of all organisms and an appreciation for environmental dynamics through time. It deepens our understanding of the environment and ecology and encourages an unsentimental respect for the natural world.

In making *EVO* I have returned to my first love: nature filmmaking. I made my first film, *A Sense of Existence* (1967), when I was 13; my goal then, as it is now, was to share my fascination and reverence for the natural world.

It is my hope that people will find ways to use *EVO* as a tool for learning about evolution and for further investigations into life in their own backyards.

John Feldman

FROM THE CURRICULUM DEVELOPER

My work at the Biological Sciences Curriculum Study (BSCS), a nonprofit organization that specializes in curriculum development, professional development, and research, included a continuing recognition and inclusion of biological evolution in our science programs. So, the need for and sensitivity to issues associated with teaching biological evolution were not new when John Feldman introduced *EVO*.

I first met John at a National Science Teachers Association (NSTA) meeting. It was in Anaheim, California, in April 2006. He told me about interviews he had of evolutionary biologists and asked how he might produce the film for science teachers.

In my years of work at BSCS, I was approached numerous times with such requests. I politely listened, accepted a DVD that contained several interviews, and told John I would review the interviews. To be truthful, I did not think the discussion would extend beyond this. I was wrong.

About a month later I noticed the DVD on my desk and decided, out of courtesy to John, to spend a few minutes reviewing the material. The quality of the filming, the location—Galápagos Islands—and the biologists left an immediate positive impression. There was no question about the need to do something that made the interviews available to science teachers.

After several unsuccessful attempts to secure funding for a project to finish the videos and prepare a teachers guide, we decided to develop the program on our own.

At BSCS, I learned about the design and development of instructional materials. Obviously, these skills became useful in this project. Work at BSCS also instilled a deep understanding of biological evolution and a profound appreciation for its importance in science education.

Science teachers have a variety of strategies and materials they use to enhance student learning. While use of video is not new or unique, it does present an option that science teachers will find exciting. The opportunity for students to see and hear renowned scientists discussing evolution, while on the Galápagos Islands, is something that will engage the students and enhance their understanding of one of the most influential theories in science.

Rodger Bybee

FROM THE AUTHORS

Like any project, we owe a considerable debt to individuals who provided their assistance. Here we extend our gratitude to Byllee Simon for her assistance and support through the entire project; to Susan Davies, a producer of *EVO*, for her dedication; and to Hugo Burgos and Carlos Montufar at Universidad San Francisco de Quito, which hosted the 2005 World Summit on Evolution.

We also acknowledge individuals who reviewed this guide: Jim Short, director, Gottesman Center for Science Teaching and Learning, Education Department at the American Museum of Natural History; Mark Terry, chair of the science department, Northwest School; and Steve Olson, award-winning author and consultant writer for the National Academy of Sciences and National Research Council. Their insights and recommendations were appreciated and substantially improved the guide.

Finally, we thank Claire Reinberg, Agnes Bannigan, and NSTA for their encouragement and contributions to the guide.

Rodger Bybee
John Feldman

INTRODUCTION

WHY TEACH BIOLOGICAL EVOLUTION?

Questioning the purpose of teaching biological evolution has certainly been paramount for many science teachers. This question holds a significant place in curricular considerations because it encompasses a continuing controversy perpetuated by some religious groups. Unfortunately, teaching biological evolution has become politicized when in fact it should be seen as a nonpartisan, scientifically supported theory. Others have advanced several compelling arguments for this position. For example, science teachers may be interested in Eugenie Scott's *Evolution vs. Creationism* (2004), Brian and Sandra Alters's *Defending Evolution in the Classroom* (2001), the National Academy of Sciences' *Science, Evolution, and Creationism* (2008), James Skehan and Craig Nelson's *The Creation Controversy and the Science Classroom* (2000), Massimo Pigliucci's *Denying Evolution: Creationism, Scientism, and the Nature of Science* (2002), and a compendium of articles for science teachers in *Evolution in Perspective* (Bybee 2004).

Biological evolution is one example of science's intellectual contributions to culture. Indeed, the theory of evolution is among the most significant scientific contributions of the 19th and 20th centuries (Mayr 2000). So, this is one among several reasons to teach biological evolution.

A second reason resides in students' questions about the natural world. After years of observations students may ask, "Why are there so many different kinds of plants and animals?" They also may ask, "How can the similarities of organisms be explained?" Teaching evolution provides scientific answers to these and many other questions that individuals ask about the natural world.

We suggest a third reason. Many life situations that students will encounter as adults are related to basic concepts of biological evolution—for example, taking the full duration of antibiotics for infections. But the importance of understanding basic concepts and processes of biological evolution goes beyond antibiotic resistance. Applications concerning the problem of invasive species and evolving viruses serve as two other examples. Science teachers can find further background and activities in *Evolutionary Science and Society: Educating a New Generation* (Cracraft and Bybee 2005) and *Evolutionary Science and Society: Activities for the Classroom* (Bybee 2006).

Finally, there is a practical reason to teach biological evolution. Biological Evolution: Unity and Diversity will be in the next generation of science standards. The National Research Council's *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC 2011) will serve as the basis for the new standards, and biological evolution is included as a core idea in the life sciences. The core idea, component ideas, and guiding questions in this new framework are the following:

1. **Evidence of Common Ancestry and Diversity:** What evidence shows that different species are related?
2. **Natural Selection:** How does genetic variation among organisms affect survival and reproduction?
3. **Adaptation:** How does the environment influence populations of organisms over multiple generations?
4. **Biodiversity and Humans:** What is biodiversity, how do humans affect it, and how does it affect humans?

Science teachers have many ways of introducing and teaching biological evolution. Options include entire courses, units of study, chapters, and individual activities. *EVO* clips and *EVO Teachers Guide* activities not only complement all of the science teachers' options, but also support science teachers in their efforts to help students meet the standards in scientifically accurate and educationally sound ways.

In addition, seldom do students have the opportunity to hear scientists talk about their work. This may be especially true if their work has to do with one of the greatest intellectual and scientific achievements in human history: the theory of biological evolution. Short descriptions and explanations by scientists, in their own words, will engage students' interest and complement other strategies. Explanations in *EVO* answer basics such as What is evolution? and Who was Charles Darwin? *EVO* also includes discussions such as What is the controversy? and Why should anyone care about evolution?

This teachers guide and the interviews of scientists on the *EVO* DVD provide a portal into one of the greatest contributions of science to society. The opportunities to enhance students' understanding of biological evolution and the processes of science serve as acknowledgement of the courage science teachers demonstrate when they answer the question, Why teach biological evolution?

WHAT IS *EVO*?

EVO is a unique DVD tool for science teachers. The DVD is organized around 10 fundamental questions about biological evolution, and some of the world's best known biologists provide answers to the 10 questions. Interviews of the biologists were gathered on the Galápagos Islands at the 2005 World Summit on Evolution, organized and hosted by the Universidad San Francisco de Quito (USFQ).

EVO is more than interviews, however. The DVD uses footage from the natural world to provide examples of the ideas and processes described by the biologists. Combined with classroom experiences, *EVO* will help students understand some of the most profound and philosophical ideas of science and develop an appreciation of the natural world.

WHO ARE THE SCIENTISTS IN *EVO*?

The World Summit on Evolution was held June 9–12, 2005, in Ecuador's Galápagos archipelago, the islands that helped spark Darwin's revolutionary ideas, which changed how we view life on Earth. The USFQ hosted this conference to celebrate the opening of its Galápagos Academic Institute for the Arts and Sciences (GAIAS). The summit brought together some of the world's preeminent evolutionary biologists and thinkers to discuss and debate current issues in evolutionary biology. The conference consisted of short presentations followed by questions, and then an open discussion between the speakers and participants.

John Feldman was invited to lead a workshop on filmmaking and to document this event. Over the course of the next five years, Mr. Feldman made *EVO*. The scientists who were interviewed for the film all attended the summit, although some of the interviews were shot after the summit. Wildlife footage for the film was shot in the Galápagos and, mostly, in the state of New York.

Scientists

Professor Leticia Aviles (University of British Columbia, Canada) focuses her research on the evolution of sociality, the evolution of sex ratios in subdivided populations, and the evolution of life history traits and local population dynamics. She has published in a variety of journals including *Evolution*, *Ecology*, and *American Naturalist*.

Professor William H. Calvin (University of Washington, United States) is a theoretical neurobiologist and the author of a dozen books, mostly for general readers, about the brain and evolution, including *A Brief History of the Mind: From Apes to Intellect and Beyond* (Oxford 2004). His book with Derek Bickerton, *Lingua ex Machina: Reconciling Darwin and Chomsky With the Human Brain* (MIT 2000), is about the evolution of structured language.

Professor Daniel C. Dennett (Tufts University, United States) is a noted philosopher whose research focuses on philosophy of mind, philosophy of science, and philosophy of biology. He is the author of more than a dozen books, including *Darwin's Dangerous Idea* (Simon & Schuster 1995). He has received two Guggenheim Fellowships, a Fulbright Fellowship, and a Fellowship at the Center for Advanced Studies in Behavioral Science. He was elected to the American Academy of Arts and Sciences in 1987.

Dr. Kevin de Queiroz (Smithsonian Institution, United States) is a research zoologist and curator at the National Museum of Natural History. His current research centers on the phylogenetic relationships of various groups of lizards. He is also interested in phylogenetic nomenclature and is the co-originator of the PhyloCode, which has been proposed to replace Linnaean taxonomy.

Dr. Niles Eldredge (American Museum of Natural History, United States) is a paleontologist and curator of the American Museum of Natural History. With

Stephen Jay Gould, he coauthored the theory of punctuated equilibria, a milestone in evolutionary theory. His specialty is the evolution of trilobites. His books include *Darwin: Discovering the Tree of Life* (W. W. Norton 2005), *Why We Do It: Rethinking Sex and the Selfish Gene* (W. W. Norton 2004), *The Triumph of Evolution and the Failure of Creationism* (Holt 2000), and *Reinventing Darwin: The Great Debate at the High Table of Evolutionary Theory* (Wiley 1995).

Professor Douglas Futuyma (Stony Brook–State University of New York, United States) is author of the popular textbooks: *Evolutionary Biology* (Sinauer Associates, 3 editions), *Evolution* (Sinauer Associates 2005, 2009) and *Science on Trial: The Case for Evolution* (Sinauer Associates 1982, 1995). His research concerns the speciation of insects and the evolution of interactions between herbivorous insects and their host plants. He is the editor of *Annual Review of Ecology, Evolution and Systematics* and has been the editor of *Evolution*. He has been president of the Society for the Study of Evolution and the American Society of Naturalists, from which he received the Sewall Wright Award. He was made a member of the National Academy of Sciences in 2006.

Professor Pierre-Henri Gouyon (Université Paris-Sud, France) is recognized for his work on evolution and genetics. He is coauthor of *Gene Avatars: the Neo-Darwinian Theory of Evolution* (Belin 1996; English translation, Springer 2002). He is the subject of a film by Nicholas Ribowski titled *Pierre-Henri Gouyon: Génétique et Evolution* (2005). He is a professor at the Muséum National d'Histoire Naturelle de Paris and at Sciences Po, Paris (École libre des sciences politiques), and he is managing editor of the European Society of Biological Evolution's *Journal of Evolutionary Biology*.

Professor Peter Grant (Princeton University, United States) and **Professor Rosemary Grant** (Princeton University) are widely known for their remarkable long-term studies of more than 35 years, which demonstrate evolution in action on Darwin's finches on the Galápagos Islands. In 2005, they received the Balzan Prize for Population Biology that praises their "seminal influence in the field of population biology, evolution, and ecology." In 2008, Peter and Rosemary Grant were among the 13 recipients of the Darwin–Wallace Medal, which is presented every 50 years by the Linnean Society of London. In 2009, they were recipients of the annual Kyoto Prize in basic sciences, an international award honoring significant contributions to the scientific cultural and spiritual betterment of mankind.

Professor Laura Katz (Smith College, United States) researches the eukaryotic tree of life, the phylogeography of coastal ciliates, and genome evolution in microbial eukaryotes. She is the editor of the book *Genomics and Evolution of Microbial Eukaryotes* (Oxford 2006) and was associate editor for the journal *Molecular Biology and Evolution* (2003–2008). She was on the scientific advisory board for the National Evolutionary Synthesis Center (NESCent) when it was newly formed (2005–2007). In addition to teaching at Smith, she is on the graduate faculty at the University of Massachusetts–Amherst.

Professor Antonio Lazcano (Universidad Autónoma de México, Mexico) is a leading scholar in the study of the origin and early evolution of life and is the author of *El origen de la vida* (*The Origin of Life* 1984). He is the first Latin American scientist to have served as president of the International Society for the Study of the Origin of Life (ISSOL).

Professor Lynn Margulis (University of Massachusetts–Amherst, United States) is renowned for her original contributions to the study of microbial evolution and cell biology. She is best known for her theory on the origin of eukaryotic organelles and her contributions to the endosymbiotic theory. Dr. Margulis contributed to James E. Lovelock's Gaia concept. Yale ecologist G. E. Hutchinson credited her with creating a "quiet revolution in microbiological thought." She received the National Medal of Science from President Clinton and Germany's Alexander von Humboldt Prize. In 2008, she was one of only 13 recipients of the Darwin–Wallace Medal, which is granted every 50 years by the Linnean Society of London. She coauthored a number of books with her son Dorion Sagan, including *Symbiotic Planet: A New Look at Evolution* (Basic Books 1998) and *Acquiring Genomes: A Theory of the Origins of Species* (Basic Books 2002). Lynn Margulis died on November 22, 2011. She was an active supporter of *EVO* and contributed much to its making. She was a courageous scientist, and we will miss her.

Professor Geoff McFadden (University of Melbourne, Australia) studies protists (eukaryotic microorganisms) and endosymbiosis. He has identified the relict chloroplast in malaria parasites and is developing herbicides as antimalarial drugs. He has published in journals such as *Nature*, *Science*, *EMBO J*, and *PNAS*. Professor McFadden has been awarded, among others, the Australian Academy of Science's Frederick White Prize, two Howard Hughes Medical Institute Scholar's awards, and the Royal Society of Victoria Medal. He is a member of the Australian Academy of Sciences.

Professor Richard Michod (University of Arizona, United States) researches the evolution of interactions within populations, particularly cooperative interactions and conflict. He has specifically examined the evolution of sex, origin of individuality, origin of life, and the evolution of social behavior. He has written *Dawinian Dynamics* (Princeton 1999), *Eros and Evolution* (Perseus 1996), and *A Natural Philosophy of Sex* (Addison Wesley 1995). He has also edited books on the evolution of sex and human values.

Professor Joan Roughgarden (Stanford University, United States) currently focuses her research on linking ecology with economic theory. Her books include *The Genial Gene: Deconstructing Darwinian Selfishness* (University of California Press 2009), *Evolution and Christian Faith: Reflections of an Evolutionary Biologist* (Island Press 2006), and *Evolution's Rainbow: Diversity, Gender, and Sexuality in Nature and People* (University of California Press 2004, 2009).

Professor Frank Sulloway (University of California–Berkeley, United States) has written about the nature of scientific creativity and published extensively on the life and theories of Charles Darwin. He is a visiting scholar in the Institute of Personality and Social Research at the University of California–Berkeley. His book, *Freud, Biologist of the Mind: Beyond the Psychoanalytic Legend* (Harvard 1979) received the Pfizer Award of the History of Science Society. Dr. Sulloway is a former MacArthur Fellow, a Fellow of the American Association for the Advancement of Science, and a recipient of the Golden Plate Award of the American Academy of Achievement.

WHAT IS THE STRUCTURE OF *EVO*?

The *EVO* DVD has 10 short videos, each based on a question. The following paragraphs summarize the 10 questions and segments and include a running time for each.

Question 1: What is evolution? (11 mins. 44 secs.)

EVO begins with a brief introduction to the World Summit on Evolution, which was the genesis for this film, and then presents the questions, What is evolution? and How long does evolution take? *EVO*'s signature arm graphic helps viewers visualize the enormous amount of time involved in the evolution of life.

Question 2: Who was Charles Darwin? (11 mins. 15 secs.)

How does Charles Darwin fit into the picture? In this brief portrait of Darwin, Frank Sulloway helps trace both the physical and mental journey that led Darwin to the idea that all organisms have evolved from a single common ancestor through natural selection.

Question 3: What is natural selection? (15 mins.11 secs.)

A joke from philosopher Daniel Dennett begins this investigation into examples of natural selection—some in the Amazon forest, some on the Galápagos Islands, but most in the filmmaker's own backyard in the mountains and forests of New York. *EVO*-style animation is used to illustrate the process, while Douglas Futuyma and some squawking birds named cocks-of-the-rock help unravel the puzzle of sexual selection.

Question 4: How do species come about? (11 mins. 1 sec.)

What is a species? Douglas Futuyma and Kevin de Queiroz tackle the "origin of species" question, and then *EVO*-style animation shows us how scientists use phylogenetic trees to visualize species splitting over time. Laura Katz clears up two common misconceptions by making it plain why humans are not descendants from chimps and why humans are not the "pinnacle of evolution."

Question 5: Where do variations come from? (9 mins. 40 secs.)

If the differences—the variations—between two individuals of the same species are the raw material for natural selection, where do these variations come from? Douglas Futuyma and William Calvin give brief introductions into genetics, DNA mutation, and sexual recombination. Then Lynn Margulis introduces the concept of symbiogenesis.

Question 6: What role does cooperation play? (9 mins. 43 secs.)

"If we form alliances with others, we can do more than going it alone," says Richard Michod as he explains that cooperation is just as important a driver of evolutionary change as competition, which usually gets all the credit. *EVO* looks at examples of cooperation ranging from human cells to ants, and hyenas to human society. Lynn Margulis introduces the Gaia idea and helps viewers see that we are all connected and part of a complex and robust Earth system.

Question 7: What is a brief history of life? (8 mins. 45 secs.)

There is evidence that the Earth formed 4.5 billion years ago and that life began approximately 3.6 billion years ago. In exactly 4.5 minutes this *EVO*-style animated film takes us along a timeline from the beginning of the Earth to the present. Niles Eldredge then reminds viewers what a young species we are and describes "punctuated equilibrium," a theory first proposed by him and Stephen J. Gould in 1972.

Question 8: What is the controversy? (9 mins. 59 secs.)

A public controversy continues over whether creationism can be taught in public school science classes along with or in place of biological evolution. Scientist Michod and philosopher Dennett look at the philosophical roots of the controversy and trace the history of the controversy with the help of Hollywood and Susan Epperson, the biology teacher who made a Supreme Court challenge in support of teaching evolution in the schools.

Question 9: Is evolution random? (8 mins. 4 secs.)

If genetic mutations occur at random, isn't evolution random? First, Douglas Futuyma defines the word *random* and clarifies the view that natural selection—the driving force of evolution—is not at all random. Daniel Dennett then describes natural selection as a sorting algorithm that is, like a computer, totally mindless. *EVO*-style animated snails, along with a careless cow, return to illustrate Futuyma's explanation of genetic drift.

Question 10: Why should anyone care about evolution? (11 mins. 36 secs.)

Evolution just happens, so why is it relevant to me? In answer to this final question, the scientists are quick to point out that we must understand evolution if we care about fighting disease and if we want to learn to live in a sustainable balance with our environment instead of degrading it. After looking at the biotechnology industry and introducing the idea of cultural evolution, John Feldman concludes *EVO* by reflecting on the importance of cooperation within the history of life and the choice each of us has to respect and care for the ecosystem of which we are a part.

HOW CAN SCIENCE TEACHERS USE *EVO*?

EVO can be used in many different ways. The only real limit is the science teacher's professional creativity. Several uses seem obvious:

1. Science teachers could use *EVO* as a unifying theme during a yearlong life science or integrated science class. Science teachers can make decisions about the best places to insert the interviews and activities within the curriculum. The *EVO* DVD and the 10 questions do not have to be used as a total program.

2. *EVO* easily complements a unit on biological evolution. Biology and life science textbooks typically include a unit on evolution. Depending on the science teacher's discretion, different videos (i.e., questions) from *EVO* could be introduced as supplements to the curriculum. The videos and their respective lessons in this teachers guide can be used in any order. For example, an application of the BSCS 5E Instructional Model (see "Ten Lessons Using *EVO*" on p. xxi) could be applied to the 10 questions and the videos used as the basis for an instructional unit. Based on the 10 questions and activities developed for this guide, the following reorganization illustrates an instructional unit:

   - Engage
     Question 1: What is evolution?
     Question 8: What is the controversy?
   - Explore
     Question 2: Who was Charles Darwin?
     Question 3: What is natural selection?
     Question 7: What is a brief history of life?
   - Explain
     Question 4: How do species come about?
     Question 5: Where do variations come from?
   - Elaborate
     Question 6: What role does cooperation play?
     Question 9: Is evolution random?
   - Evaluate
     Question 10: Why should anyone care about evolution?

3. Science teachers could use the 10 videos and complementary activities as a short course. Using the DVD as a central feature and adding investigations, readings, and classroom presentations, the lessons and resources included in this guide could serve as the supplements to create such an introductory course. The lessons included in this guide are only intended as optional supplements for science teachers.

4. Finally, science teachers could use the interviews as the basis for students' independent study. Science teachers would use their judgment about the parameters of individualized or differentiated study, but the interviews and questions certainly provide an excellent place for students to begin study as well as begin a range of research projects identified within the *Look-Again* markers in the *EVO* DVD.

The *Look-Again* markers are an index to *EVO's* significant thoughts and moments. Clicking on a *Look-Again* menu item takes you to that point in *EVO*. To stop playing and return to the *Look-Again* menu, push Menu on your remote control. While playing *EVO*, you can use the Forward, Next, or Next Chapter button your remote to jump from one marker to the next.

TEN LESSONS USING *EVO*

The 10 lessons for *EVO* have a clear focus on different aspects of evolution. Concepts such as natural selection and genetic variation as well as understanding the scale of time for evolution are the learning outcomes. The lessons have two additional features: (1) They are based on the 5E Model, which will enhance student learning of the biological concepts, and (2) the lessons include opportunities that will help students develop skills important in the 21st century. The following discussion provides a background on the 5E Model and 21st-century workforce skills found in the *EVO Teachers Guide* lessons.

THE BSCS 5E INSTRUCTIONAL MODEL

The *EVO Teachers Guide* lessons incorporate the 5E Model. The instructional model includes five steps: (1) engagement, (2) exploration, (3) explanation, (4) elaboration, and (5) evaluation of science concepts and processes. The following discussion provides details of the five stages.

ENGAGE THE STUDENTS.

This stage of the instructional model initiates the learning task. The activity makes connections between past and present learning experiences and anticipates activities and helps focus students' thinking on the learning outcomes of current activities. Students should become mentally engaged in the concept, process, or skill of the lesson.

Scientific investigations of biological evolution originate with a question that engages a scientist, so too must students engage in the activities of learning. The *EVO Teachers Guide* lessons begin with a strategic question that gets students thinking about the content of the lesson.

STUDENTS EXPLORE THE TOPIC.

This stage of the instructional model provides students with a common base of experiences within which they identify and develop current concepts, processes, and skills. During this stage, students actively explore their environment or manipulate materials.

Once engaged, students need time to explore ideas before concepts begin to make sense. In this exploration stage, teachers provide opportunities for students to try their ideas, ask questions, and look for possible answers to questions. In the *EVO Teachers Guide*, students use inquiry strategies and try to relate their ideas to those of other students and to what biologists already know about evolution.

STUDENTS, TEACHERS, AND SCIENTISTS PROVIDE EXPLANATIONS.

This stage of the instructional model focuses students' attention on a particular aspect of their engagement and exploration experiences and provides opportunities for them to develop explanations and hypotheses. This phase also provides opportunities for teachers to introduce a formal scientific label or definition for a concept, process, or skill.

In the *EVO Teachers Guide* lessons' third step, students propose answers and develop hypotheses. Also in this step, *EVO* has an especially strong place for introducing the scientists and their explanations of the various aspects of biological evolution. This also is the step when teachers should make the major concepts explicit and clear to the students.

STUDENTS ELABORATE THEIR UNDERSTANDINGS AND SKILLS.

This phase of the instructional model challenges and extends students' conceptual understanding and allows further opportunity for students to test hypotheses and practice desired skills. Through new experiences, the students develop a deeper and broader understanding, acquire more information, and develop and refine skills.

Science teachers understand that informing students about a concept does not necessarily result in their immediate comprehension and understanding of the idea. So the *EVO Teachers Guide* lessons provide a step referred to as elaboration in which students have opportunities to apply their ideas in new and slightly different situations.

EVALUATE STUDENTS' UNDERSTANDING AND SKILLS.

This stage of the instructional model encourages students to assess their understanding and abilities and provides opportunities for teachers to evaluate student progress toward achieving the learning outcomes.

Teachers need to assess how well students understand the concepts, or how successful they are at applying the desired skills. These are the questions to be answered during the evaluation stage. In the *EVO Teachers Guide* lessons, we have provided a single rubric for science teachers to use in the evaluation stage.

This use of the 5E Model usually centers on a daily lesson as the parameters for the instructional sequence. In other cases, the instructional sequence is longer, perhaps several days or a series of lessons that amount to a unit of study. Although a longer instructional sequence provides greater opportunities for students to learn, we wanted to focus on the *EVO* interviews, without assuming an extended time, and leave additional activities to the science teacher's professional discretion. Each of the questions (i.e., DVD segments) represents a topic of study that is appropriate for individual or group work.

21st-CENTURY WORKFORCE SKILLS

These lessons for the *EVO* DVD provide opportunities to develop different skills and abilities that students will need as they prepare for college and careers. The opportunities to develop the following skills present themselves in any inquiry-oriented classroom where students interact, problem solve, communicate findings, complete homework, and engage in serious thought about scientific explanations about evolution.

ADAPTABILITY

In some *EVO* lessons, students will be required to cope with new approaches, grapple with new explanations, and work with new tools and techniques. In addition, in some cases, students will work in groups. In all of these cases, science teachers have the opportunity to help students develop adaptability.

COMPLEX COMMUNICATIONS/SOCIAL SKILLS

Lessons with varied learning experiences, including investigations, will require students to process and interpret information and data from a variety of sources. Learners would have to select appropriate evidence and use it to communicate a scientific explanation. Some *EVO Teachers Guide* lessons include group work that culminates with the use of information to formulate a conclusion or recommendation.

NONROUTINE PROBLEM SOLVING

Some lessons require learners to apply knowledge to scientific questions and technological problems, identify the scientific components of a contemporary issue, and use reasoning to link evidence to an explanation. Students may be required to think of another explanation, or another way to gather data, and connect those data with their knowledge.

SELF-MANAGEMENT/SELF-DEVELOPMENT

EVO Teachers Guide lessons include opportunities for students to work on activities individually and collaboratively. These activities require learners to acquire new knowledge and develop new skills as they pursue answers to questions or solutions to problems.

SYSTEMS THINKING

Some *EVO Teachers Guide* lessons include the introduction and applications of systems thinking in the context of life science as well as multidisciplinary problems in personal and social perspectives. Learners may be required to realize the limits to systems; to describe components, flow of resources, and changes in systems and subsystems; and to reason about interactions at the interface between living systems.

Table 1 summarizes essential features of the skills and provides examples for school science programs.

As you will see, not all skills are a part of each lesson. Only those skills appropriate to the *EVO Teachers Guide* lesson are presented.

Table 1. Developing 21st-Century Skills in Science Programs

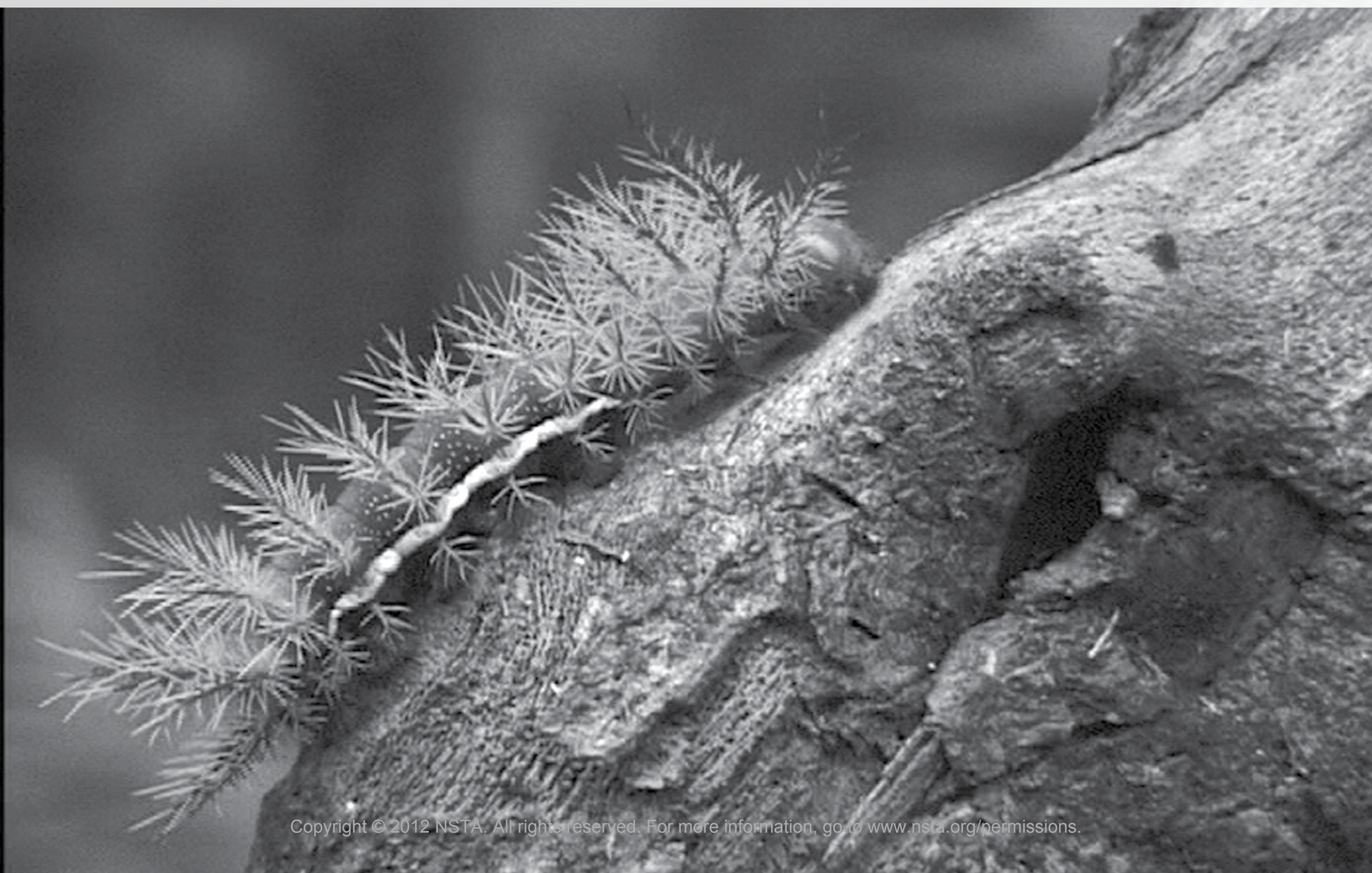
Essential Features of 21st-Century Skills	Examples of Contexts for School Science Programs
Adaptability	
• Cope with changing conditions • Learn new techniques, procedures • Adapt to different personalities and communication styles • Adapt to different working environments	• Work on different investigations and activities • Work on different activities • Work cooperatively in groups • Work on lessons in different situations
Complex Communications/Social Skills	
• Process and interpret verbal and nonverbal information • Select key pieces of complex ideas to communicate • Build shared understanding • Negotiate positive outcomes	• Prepare oral and written reports communicating procedures, evidence, and explanations of investigations and activities • Use evidence gained in investigations as the basis for a scientific explanation • Prepare a scientific argument • Work with group members to prepare a report
Nonroutine Problem Solving	
• Use expert thinking in problem solving • Recognize patterns • Link information • Integrate information • Reflect on adequacy of solutions • Maintain several possible solutions • Propose new strategies • Generate innovative solutions	• Recognize the need for an expert's knowledge • Recognize patterns in data • Connect evidence and information from an investigation with scientific knowledge from the video, teachers, or other sources • Understand constraints in proposed solutions • Propose several possible solutions and strategies to attain the solutions • Propose creative solutions
Self-Management/Self-Development	
• Work remotely (individually) • Work in virtual teams • Develop self-motivation • Develop self-monitoring • Display willingness and ability to acquire new information and skills	• Work individually at home • Work with a virtual group • Complete a full/open activity • Reflect on adequacy of progress, solutions, and explanations • Acquire new information and skills in the process of problem solving and working on an investigation
Systems Thinking	
• Understand the systems concept • Understand how changes in one part of the system affects the system • Adapt a "big picture" perspective • Complete system analysis • Demonstrate judgment and decision making • Apply abstract reasoning about interactions among components of a system	• Describe components of a system based on a system under investigation • Predict changes in an investigation • Analyze a system under investigation • Make decisions about best proposed solutions • Demonstrate understanding about components and functions of a proposed system

LESSON NINE:
Is Evolution Random?

OVERVIEW

This lesson begins with students observing and explaining patterns in nature. They confront the issue of explaining patterns in nature using natural processes or purpose. They conduct a simple activity of sorting gravel, sand, and ash and observe the patterns and physical process. Then, the students are asked the question, Is evolution random? They view the *EVO* DVD and learn about randomness, patterns, and purposeful explanations. Finally, they apply their understanding to a new problem presented in the final segments of the *EVO* DVD.

Time: One 50- to 55-minute class period **DVD: 8 mins. 4 secs.**



LEARNING OUTCOMES

As a result of this lesson students should be able to

- recognize patterns in nature as the result of physical/natural processes,
- describe randomness as applied to genetic variations,
- explain selection as a natural process, and
- combine the randomness of genetic variation and the algorithms of natural selection as an answer to the question, Is evolution random?

MATERIALS FOR THE LESSON

- Equipment to play the *EVO* DVD for the entire class and computer workstations for students to view the *EVO* DVD during group classwork. Arrange groups of four to five students each.
- Several (three to four) pictures of patterns in nature (e.g., cross-sections of a nautilus, sunflower, leaves, frost crystals, honeybee combs, pebbles sorted on a beach, similar species of animals and plants)
- Each group of students will need the following:
    - One 25 ml graduated cylinder
    - A mixture of gravel, pebbles, sand, and ash
    - A source of water

BACKGROUND FOR THE TEACHER

This lesson centers on three ideas—randomness, patterns, and purpose—as they relate to natural phenomenon in general and biological evolution in particular. The *EVO* DVD presents explanations for genetic mutations; they are random. The DVD presents scientists explaining natural selection: It is not random, but natural selection lacks purpose. As these are relatively complex ideas, the lesson uses observable patterns in nature as a way to help students understand the process and answer the question, Is evolution random?

Simple patterns in nature can be explained in terms of natural processes. For example, as rivers reach lakes, they deposit their "load" (i.e., rocks and other material) based on mass, density, etc. Larger rocks are deposited before smaller pebbles, and there is a natural gradation, or sorting.

Complex patterns in nature may be more difficult to explain. The processes of biological evolution demand explanations that are more difficult to comprehend. Due to these processes' complexity, some people suggest a designer with a purpose. Purposefulness is a possible nonscientific explanation, but biological evolution can be explained without evoking purpose. Ever since Darwin, scientists have developed increasingly detailed scenarios for the development of all sorts of eyes based on comparing anatomy, paleontology, and comparative genomics.

Darwin's theory of evolution proposes two steps that result in the complexity of living organisms. First, there are random changes in the genetic makeup of individual organisms. Second, there is exposure to selective pressures or forces and only some individuals with some variations survive and reproduce. In time, the genetic variation in the population changes toward those characteristics with greater survival and reproductive advantages. These processes, in extended periods of time, produce unity and diversity in the living world. The cumulative process of selection is not purposeful. Yet to answer the lesson's question, evolution is not random. The lesson should help students understand that scientists can explain patterns such as evolution without appealing to a designer or ultimate purpose.

PREPARING FOR THE LESSON

- Review the *EVO* DVD. Go to the menu's Select A Question, and review Question 9, Is evolution random?
- Set up equipment (e.g., a computer or DVD player) for class presentation.
- Set up materials for the demonstration.

LEADING THE LESSON

ENGAGE the Students. (5 mins.)

1. Begin by showing the students actual examples of natural patterns. Alternatively, pictures of patterns in nature are appropriate. The examples might include hexagon-shaped cells of a honeybee hive and seashells.
2. Ask the students to identify other examples of patterns in nature.
3. Ask them how they would explain the formation of patterns in nature. Are the patterns random? The students are likely to provide a variety of definitions and explanations, some in nature and others not natural. As this is the Engage stage, accept all the students' suggestions.

EXPLORE Patterns, Purpose, and Randomness in Nature. (20 mins.)

1. Assign students to groups of four to five and distribute graduated cylinders (25 ml), gravel, sand, and ash to each group. Provide a source of water.
2. Have the students observe and describe the gravel, sand, and ash.
3. Ask them to predict what will happen if the mixture of gravel, sand, and ash is added to the cylinder filled with water. Students will likely say that the gravel will go to the bottom with sand and ash sorting out in that order.
4. Have them place the mixture of gravel, sand, and ash in the cylinder.
5. Have them explain the process of sorting that they observed. Students will explain the process using terms such as *density*, *gravity*, *friction*, or *buoyancy* as the reason the particles formed layers.

6. Conclude this phase of the lesson by asking if the pattern they observed was random? Was there a purpose? Help them with a clarification of these terms using the activity as the context for the exploration.

EXPLAIN Patterns, Purpose, and Randomness in Evolution. (20 mins.)

1. Ask the students Question 9 from the *EVO* DVD. To the students: *Is evolution random?* Accept their answers. Listen for their use of concepts and processes from prior lessons and activities.
2. Show the *EVO* DVD.
3. Ask the students to apply what they know and heard on the DVD and answer the question, Is evolution random?
4. Use the *Look-Again* markers to return to sections to help the students understand the relationship between the randomness of genetic mutations and the processes of natural selection. *Look-Again* will direct viewers to the following:
   - random defined
   - sorting algorithms
   - nat. selection not random, swan sailing
   - genetic drift, snails and cows animation

ELABORATE the Students' Explanations.

1. Use the *Look-Again* markers to show the section on genetic drift, snails and cows animation.
2. Ask the students to use the terms *random*, *natural selection*, and *patterns* to explain what the scientist Futuyma explained.

EVALUATE Students' Learning.

Use the following criteria for evaluating students' learning:

Exceeds expectations: All outcomes are met, work goes beyond expectations and demonstrates exceptional understanding.

Meets expectations: Work indicates that student understands major issues and concepts.

Below expectations: Student work does not meet the criteria. It may be incomplete or may not address key issues or concepts of the learning outcomes.

Learning Outcomes	Evaluation
Recognize patterns in nature as the result of physical/natural processes Describe randomness as applied to genetic variations Explain selection as a natural process Combine the randomness of genetic variation and the algorithms of natural selection as an answer to the question, Is evolution random?	
Overall evaluation for this lesson	

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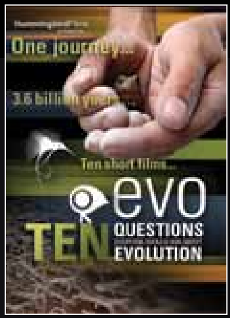
EVO TEACHERS GUIDE: TEN QUESTIONS EVERYONE SHOULD ASK ABOUT EVOLUTION

This teachers guide enables you to effectively use the *EVO* DVD to take your students on a journey to the Galápagos Islands with some of the world's most well-known, inspiring biologists. The DVD, shot during the World Summit on Evolution, goes beyond interviews. It provides perspectives on the natural world that will give your students vivid examples of the ideas and processes the biologists describe. The rigorously structured teachers guide will give you lesson-by-lesson learning outcomes, thorough background, and guidance on preparing for and then leading the lesson—from initial student engagement through evaluation.

Among the vital questions you and your students will explore:

- What is evolution?
- Who was Charles Darwin?
- What is natural selection?
- How do species come about?
- Why should anyone care about evolution?

Easy to use and authoritative, *EVO Teachers Guide* and the accompanying DVD are must-have resources. As author Rodger Bybee notes in the Preface, "The opportunity to see and hear renowned scientists discussing evolution while on the Galápagos Islands is something that will engage the students and enhance their understanding of one of the most influential theories in science."



Check out the *EVO* DVD at www.nsta.org/store!

Grades 9–12

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