Virus and the Whale

Exploring Evolution in Creatures Small and Large

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Judy Diamond, *Editor*

With Carl Zimmer, Linda Allison,
E. Margaret Evans, and Sarah Disbrow

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Preface

Judy Diamond
Director
Explore Evolution project

For the past two decades, my family and I have conducted field research on the behavior and evolution of two species of parrots from New Zealand (Diamond and Bond 1999). Over the years, we compared and contrasted the behavior of these closely related species to see where common patterns reinforced common ancestry, or where different patterns suggested adaptations to diverse environments.

As young field researchers, my children understood that evolution was part of how our family viewed the natural world. However, each time they returned from the field to their classrooms in Lincoln, Nebraska, they encountered strong denials of our ideas. Many of their classmates dismissed any possibility that evolutionary ideas were correct or relevant. Our children often asked us how we, as parents, could be so sure that our ideas were right, and how so many other children and their parents could be so wrong.

The Explore Evolution project started as a way to help young people and adults gain some of the experience of what it is like to study evolution as a scientist. Most biological scientists view the world from an evolutionary perspective. The geneticist Theodosius Dobzhansky said in 1964, "Nothing in biology makes sense except in the light of evolution." This is as true today as it was 40 years ago (Dobzhansky 1964).

In biology, thinking like a scientist is, in large part, thinking about evolution. As educators, our task is to help young people feel what it means to view the world from a scientific and evolutionary perspective. This book invites you to engage youth in activities that are based on current research projects that have had a major influence on how scientists today think about evolution.

Designed to be used with middle-school-age youth, the activities in this book work in almost any setting, they are youth-centered, and they are designed to encourage social interaction. Each of the seven activities incorporates concepts of inquiry-based learning and the 4-H Youth Development experiential learning model. Along with the activities, the book provides many resources for teachers and youth leaders. The first section presents an overview of what you need to know about how to use this book with kids. It includes learning outcomes for each activity tied to the National Science Education Standards, assessment questions, and materials needed. The first chapter, by Carl Zimmer, gives an introduction to evolution for those who want for more background on the topic. The second chapter, also by Carl

Zimmer, gives background information on the evolution of each of the seven organisms that are investigated in this book. The third chapter, by Margaret Evans, helps introduce teachers and youth leaders to common ways that children and adults think and learn about evolution.

This book is a product of the Explore Evolution project, a partnership forged between science museums and 4-H organizations in the Midwest to bring current research on evolution to middle school youth, educators, and the general public. Our museum partners include the Exhibit Museum of Natural History of the University of Michigan, the Kansas Museum and Biodiversity Center at the University of Kansas, the Sam Noble Oklahoma Museum of Natural History at the University of Oklahoma, the Texas Memorial Museum at the University of Texas at Austin, the University of Nebraska State Museum and the Science Museum of Minnesota. Our 4-H partners are the statewide 4-H Youth Development programs in Iowa, Minnesota, Nebraska, Texas, and Wyoming. The Explore Evolution project has produced new permanent exhibit galleries for the partner museums. This book is designed in parallel with the galleries—to be used independently or in conjunction with the exhibits. The exhibits and the book focus on the same seven current and influential evolutionary research projects.

The central theme of Explore Evolution is to show common patterns and principles in the evolution of organisms ranging in size from viruses to whales. The secondary theme is to show how scientific research uncovers new ideas about how the natural world operates, and how these ideas are continuously modified by new research. Overall, we emphasize that evolution is the central unifying principle for a scientific understanding of the natural world. The book provides durable, hands-on and easy-to-use activities to bring investigations about evolution to youth in any of the settings where they can do science with their peers.

Acknowledgments

This book represents a huge effort on the part of many people. Foremost, we are indebted to the scientists who provided us with the fascinating research projects that are the subject of this book, and who also worked with us wholeheartedly throughout this enormous undertaking. For this, we thank Cameron R. Currie, University of Wisconsin; Sherilyn C. Fritz, University of Nebraska-Lincoln; Philip D. Gingerich, University of Michigan; B. Rosemary and Peter R. Grant, Princeton University; Henrik Kaessmann, University of Lausanne, Switzerland; Kenneth Y. Kaneshiro, University of Hawaii at Manoa; Svante Pääbo, Max Planck Institute for Evolutionary Anthropology; Edward C. Theriot, University of Texas at Austin; and Charles Wood, University of Nebraska-Lincoln.

We also recognize the support given to us by the museums that participated as partners in the Explore Evolution project. For their commitment to the project, we acknowledge and thank museum directors Ellen J. Censky of the Sam Noble Oklahoma Museum of Natural History at the University of Oklahoma, Priscilla Grew of the University of Nebraska State Museum, Amy Harris of the Exhibit Museum of Natural History at the University of Michigan, Eric Jolly of the Science Museum of Minnesota, Leonard Krishtalka of the Natural History Museum and Biodiversity Research Center at the Uni-

versity of Kansas, and Edward Theriot of the Texas Memorial Museum at the University of Texas at Austin.

Many museum staff members played significant roles in making this book possible. Foremost, we thank Angie Fox for her outstanding illustrations, which appear throughout in the book and the exhibit, and for her help in producing the book graphics. We also thank Katrina Hase, Rob Sharot, Roger Barrett, Paul Martin, David Chittenden, and many others from the staff of the Science Museum of Minnesota who played a central role in developing the exhibit galleries. Debra Meier, Joel Nielson, and Ron Pike (Nebraska), John Klausmeyer (Michigan), Brad Kemp and Bruce Sherling (Kansas), and John Maisano (Texas) contributed valuable expertise to the project and assisted in the development of exhibits and in the overall organization of the Explore Evolution project.

Several individuals deserve special mention for the assistance they provided to the project. We greatly appreciate the advice of John West for his critical help in the virology activity and exhibits. We also thank Lisa Diamond of the Stanford Genome Technology Center for her valuable help in developing the human-chimp gene comparison graphic. Finally, we thank Judy Scotchmoor of the University of California Museum of Paleontology for her unfailing support and many useful suggestions.

We are also indebted to the efforts of many individuals whose work greatly enhanced the quality and usefulness of this book. The Explore Evolution Nebraska outreach team, coordinated by Kathy French, and assisted by Cindy Loope, Eileen Cunningham, Estella Wolf, and Ann Cusick, trial tested the book with middle school children at several stages of its development and gave us much valuable advice. We also thank the 38 middle school kids who participated in the trial testing and gave us such valuable feedback.

The Explore Evolution evaluation team, coordinated by Amy Spiegel, Wendy Gram, and Margaret Evans, and assisted by Deborah Kay, Cindy Loope, Brandy Frazier, Sarah Cover, and Medha Tare, provided valuable feedback and guidance throughout the development of the book and exhibit. Many 4-H leaders and museum educators have advised us throughout the course of this project and have played an important role in disseminating this project to youth leaders, teachers, and children. We thank all of them, and, in particular, Bradley Barker, Elizabeth Birnstihl, Stephen Carlson, Catherine Denison, Dianne Folkerth, Gene Gade, Lilliane Goeders, Teresa MacDonald, Robert Meduna, and Jay Staker.

We owe a special thanks to our partners and children, Alan, Benjamin, and Rachel; David, Anna, and Vanessa; Gus Buchtel; and William Wells, for supporting us during this project.

For guiding the project through the many stages from manuscript to publication, our thanks go to our editor Claire Reinburg, project editor Andrew Cocke, graphic designer Linda Olliver, and production director Catherine Lorrain-Hale at the NSTA Press.

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Introduction

Eugenie C. Scott
Executive Director
National Center for Science Education, Inc.

A few years ago a publishing house editor told me I should write a book about my one-of-a-kind job as executive director of the National Center for Science Education (NCSE). NCSE defends the teaching of evolution in the public schools and opposes the teaching of religious views as science. I get to do a lot of public speaking and writing about the creationism/evolution controversy, and some radio and television work, which is fun. Mostly I work with my colleagues to advise people around the country on what to do when the issue of teaching evolution becomes controversial in a community or state. She said I should title the book, "Evangelist for Evolution."

I blanched.

What came to mind was an exchange with Duane Gish, debater extraordinaire of the Institute for Creation Research, on a radio call-in show. Duane said (as he had said many times before) "evolution is just as religious as creationism." I was sufficiently exasperated at yet again hearing this old saw to snap, "If evolution is a religion, it's a damned uninspiring one." And indeed, even though the scientific establishment concurs that living things are related through common ancestry, and even though university science libraries are laden with books and journals matter-of-factly discussing evolution, this central scientific idea does not inspire people to defend it with any where near the zeal of people attacking it. (We are especially aware of this when we compare the, ahem, finances of NCSE to that of the several major creationist organizations!)

Well, I didn't write Evangelist for Evolution—I wrote a different book (Scott 2004). Yet I think maybe someday I will, though not because evolution is a religion. Evolution is not a religion. I repeat. Evolution is not a religion. There is no "church of Darwin," evolutionists do not have rituals (not even a secret handshake), and no one is going to get salvation from "believing" in natural selection (or rejecting it). (If you don't know what natural selection is, hang in there; you'll read about it later in this book.) But religion is why evolution is viewed as controversial by so many Americans. A Gallup poll found that even though only 5% of scientists agreed with the statement "Humans were created by God in their present form about 10,000 years ago," 47% of the general public agreed (Witham 1997). I believe that the reason for the large percentage of rejection of evolution in the United States (though interestingly, not in other developed countries) is that people confuse evolution with atheism: they believe that they have to

choose between evolution and God, between science and religion.

Unfortunately, Americans are not only illiterate in science, they are theological illiterates as well. Most are unaware that although some religious traditions (such as biblical literalism) are incompatible with evolution, literalism is not the dominant tradition in either Christianity or Judaism, the two largest faiths in the United States. Catholic parochial schools routinely teach evolution; Catholic and mainstream Protestant theologies reflect varieties of "theistic evolution:" that God created through the process of evolution. They do not believe in Genesis literalist special creationism, which is that God created everything all at one time, in its present form (and usually only about 10,000 years ago or less). Alas, there are many Catholics and mainstream Protestants who don't know their denomination's theology! But as an educator, you will need to deal with these misunderstandings. If a visitor says to you, "I'm a creationist" you might want to ask, "What kind?" because to many people the word *creationist* means that God created, on which all Christians, Jews and Muslims agree. Identifying as a creationist doesn't necessarily identify one as a special creationist: Someone describing him or herself as a creationist might be a theistic evolutionist. Pope John Paul, for example, was one of these creationists (he believed God created) who also accepted evolution. The confusion of terminology about who is a creationist only adds to other confusions about evolution and religion, but at least it is fairly easy to clear up.

The tough issues, though, go beyond definitions and concern God's involvement in creation. Is God guiding evolution? Is there a goal to evolution? Is there an ultimate purpose to the universe? If there are answers to these questions, they won't come from science, but from theology. Because science explains using only natural cause, it can't be used to test supernatural explanations. Obviously, an omnipotent power can create any way it wants, including all at once, or gradually through evolution—or create all at once and make it look like evolution happened. Any explanation is compatible with an omnipotent Creator, so therefore creationist claims cannot be tested. If a statement can't be tested against the natural world, it isn't a scientific statement. Using science, one cannot say whether God did or did not create, nor can the methods of science offer guidance about whether God is the ultimate cause of everything. Science is a limited way of knowing, limited to explaining only the natural world, and restricted to natural causes.

But as the philosopher once said, "To say nothing of God is not to say that God is nothing." If science explains things without mentioning God, that doesn't mean that science is saying, "God had nothing to do with it." It's funny: No one accuses science of ignoring God when we try to explain cell division. If a scientist says, "Enzyme X causes the cell to begin to divide, and enzyme Y causes spindle fibers to form, and enzyme Z causes the chromosomes to line up in the middle," no one castigates him/her for not mentioning "because God wanted the chromosomes to line up in the middle." We don't expect scientists to bring up God while explaining cell division—so why do some people get upset when we don't bring up God when talking about evolution? But people do get upset, and you will need to help them understand why such explanations are outside of science, and that indeed—unless they are special creationists—science is not challenging

their religious views. Indeed, to say nothing of God is not to say that God is nothing.

What science *can* tell us, however, is that the evidence is overwhelming that species have a genealogical relationship, and that the pattern of evolution seen through the fossil record does not appear to be heading toward any particular goal. In the Miocene, we see a variety of horse adaptations: some browsers, some grazers, some with three toes, and some with one toe. Viewing those different adaptations used by horses 20 million years ago doesn't allow us to predict that one million years ago in the Pleistocene, only one-toed grazers would be left. Did God intend that *Equus* (the genus that includes the modern horse) would be the "winner" in the evolutionary game? Science can't say. Out of all the ape species of the Pliocene, did God intend a bipedal one with an opposable thumb to eventually give rise to *Homo sapiens*? Science can't say. These are theological questions, not scientific ones. Science describes what happened, when, and where; only philosophy and religion can speculate as to the ultimate meaning or ultimate cause of what happened.

This means religious individuals are free to hold most beliefs about God's involvement with evolution if they choose; there is nothing in the scientific understanding of evolution that prohibits someone from believing that God is the ultimate cause of everything in the universe, or even that God could be guiding evolutionary events. But it is not possible to verify such statements through science.

As you read the following book, I think you will agree that evolution is an exciting scientific idea. Students should know about it, for the sheer intellectual joy of the experience. I remember when I was in high school, my biology teacher, a kindly old gray-haired man named Mr. Rasmussen, did not teach us evolution, and I don't recall it being in the textbook. One day after school a friend and I were talking to him and one of us asked him about why there were so many different kinds of animals. He said, "Well, some people believe that some animals are better able to live in an environment than others, and they have more offspring and that kind comes to dominate in that environment, and the population gradually becomes different through time."

My head reeled. This was such a wonderful, simple explanation, and it made so much sense (it is the essence of Darwinian natural selection, a prime mechanism of evolution). I remember becoming terribly excited, and brimming over with questions. I wanted to know everything—did this explain why we no longer had dinosaurs around? Did people change like this? Before I could say anything, though, Mr. Rasmussen quickly added, "Of course, some people think that God created all the animals like they look today."

I hesitated. It sounded like I was being given the choice between science and religion, and I didn't want to sound like I was being antireligious. But so many questions wanted to tumble out! But Mr. Rasmussen held a finger to his lips, conspiratorially, and said, "Shhhhhhh," as he eased us out of the classroom and closed the door.

That was the end of my evolution instruction until college, and even today, more than 40 years later, many students are similarly denied the excitement of learning this simple but elegant theory. I hope you, as teachers, youth leaders, or museum curators, can help people begin to appreciate evolution, and how it helps us make sense of so much of the living world. It is an important job and a very worth-

while one—and it will be made enjoyable by the activities you will be leading the children through.

Because even though evolution is not a religion, it is sorely in need of someone to tell people about it. At NCSE, we try to help people understand evolution—why they need not be afraid of it, and why their kids should be taught it in school. You also have the opportunity to help students and others to understand this quite astonishing idea that explains so much about nature. You don't have to be an evangelist for evolution, but you can certainly open up what for many people will be a new area of knowledge which is likely to lead to some profound understandings of living things.

I wish you success—and the enjoyment of sharing exciting scientific ideas!

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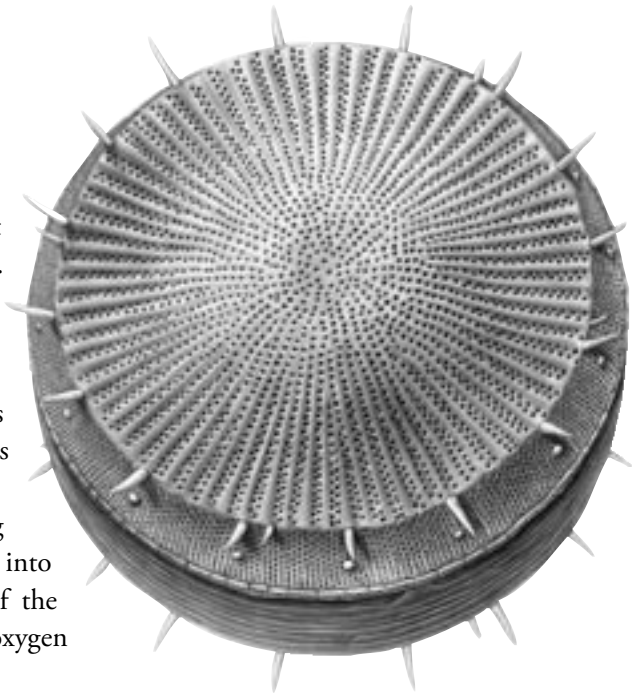
DIATOMS: One-Celled Wonders



Diatoms (DIE-a-toms) are one of the most important things you never knew about. They are everywhere there is water. A drop of lake water is packed with them. You probably swallow millions every time you go swimming. These tiny, one-celled life forms populate the world's ponds, rivers, and oceans (and anywhere else that's the least bit wet). They spend their invisible lives quietly using sunlight to turn carbon dioxide and water into food and oxygen. Diatoms are the basis of the food chain, and they produce much of the oxygen you breathe.

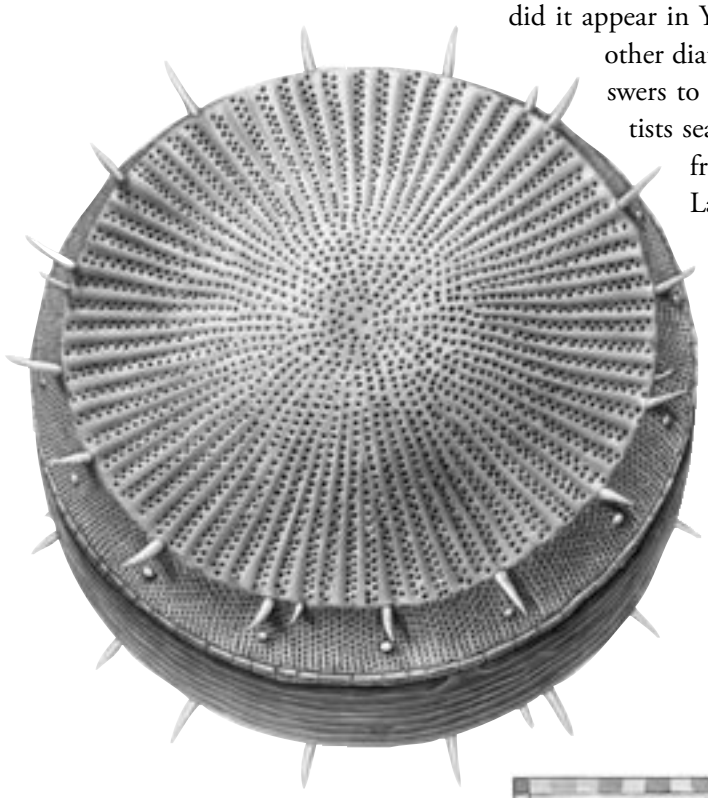
Dead or alive, diatoms are important. Their skeletons are made from a substance called silica, which is the main ingredient in glass. When diatoms die, their dead bodies pile up by the trillions on the floor of oceans and lakes, forming a chalky mud. This plentiful mud is used as a water filter, an insecticide, and even as an ingredient in some toothpaste.

More important still, dead diatoms fossilize (become preserved) over time. The fossil record can tell us many things about Earth's past, and diatoms are especially good record keepers. First, their fossils are plentiful. A dollop of mud the size of an ice cube may contain as many as 50 million well-preserved diatoms. Second, there are many different kinds of diatoms. No one knows the exact number, but scientists estimate a quarter of a million species, each one preserving a unique record of the past. And third, diatoms are so sensitive to changes in temperature and moisture that the presence or absence of a particular species can tell us a great many things about the environment. From the rise and fall of different diatom populations, we can learn

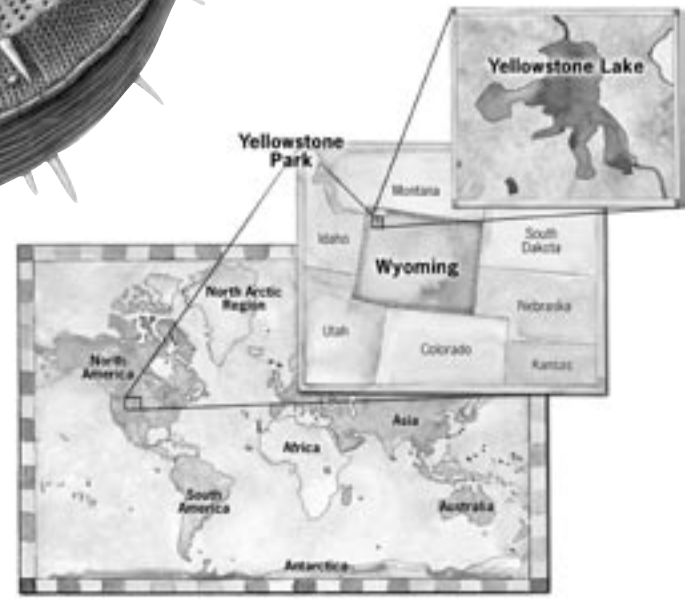
about changes in past climates, which in turn can give us more clues about the world that plants and animals occupied in the past.

This is where four scientists, a famous lake, and a mysterious diatom enter our story. Brian Shero, a professor at a small New York college, was studying diatoms in Yellowstone Lake when he found a diatom he had never seen before. He sent it to a diatom expert, Edward Theriot, to identify. Ed's life goal has been to learn everything he can about diatoms. He was surprised and excited to discover a diatom he didn't know. It was a species that was brand new to science, and more amazing still, there was no record of it living anywhere else on Earth. In honor of its hometown lake, the new diatom was named *Stephanodiscus yellowstonensis* (Steff-ah-no-DISK-us yellow-stone-EN-sis), which means crowned disk of Yellowstone.

Ed was curious about the origins of the mysterious diatom. How and when did it appear in Yellowstone Lake? Did it arise from some other diatom species already there? To find out answers to these questions, Ed and a team of scientists searched for fossil diatoms in mud samples from the bottom of the lake. Yellowstone Lake was formed after the last Ice Age, around 14,000 years ago. Ever since then diatoms have lived and died in the lake. Their sinking skeletons have built up fossil deposits dozens of feet thick, creating a unique time line for scientists to study.



The name of the diatom *Stephanodiscus yellowstonensis* means "crown disk of Yellowstone."
UNSM Angie Fox illustration



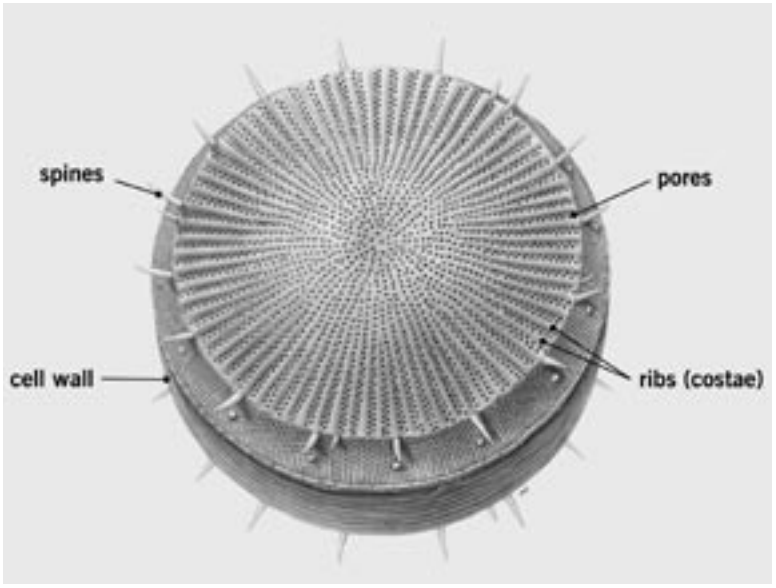
Yellowstone Lake is located in Yellowstone Park.
SMM Lonnie Broden illustration

Yellowstone Lake in Yellowstone National Park contains a species of diatom that is found nowhere else.
Photo courtesy Joe Sawyer

Scientists take a core sample from beneath Yellowstone Lake.
Photo courtesy Edward Theriot

To actually see the fossil deposits is difficult work. The scientists drove a tube a few inches wide and as long as a telephone pole down through hundreds of feet of water and lake-bottom sediments. Sediments in a lake settle gently year by year, forming undisturbed layers often as distinct as the layers of a birthday cake. When the long tube was pulled up, it revealed layers of mud in clear stripes. Each stripe represented a year of diatoms. "We can look in there and find the sediment from 11,298 years ago, in the summer," Ed says. The core sample covered the entire geological history of the lake, from its birth 14,000 years ago to the present.

What Ed found in the core sample blew him away. By identifying and counting diatoms sample by sample, he could see evolution in action. When Yellowstone Lake first formed, a diatom lived there called *Stephanodiscus niagarae* (Ny-ah-gary), the Niagara diatom. There was no sign yet of *S. yellowstonensis*, the Yellowstone diatom. Over the next 4,000 years, some Niagara diatoms began to change, resembling *S. yellowstonensis* more and more. "We can watch, literally watch, as these diatoms go from one species to another," Ed exclaimed. In the core sample, the scientists were able to find



The diatom *Stephanodiscus yellowstonensis* (right) has about five ribs between each spine. Counting the ratio of spines to ribs is the way diatom experts tell this species from similar ones.
UNSM Angie Fox illustration

Edward Theriot (below) is a diatom scientist at the University of Texas at Austin.
Photo courtesy Marsha Miller

Sheri Fritz (bottom) studies how climate change influences the evolution of diatoms.
Photo courtesy Tom Simons University of Nebraska-Lincoln.

a diatom that had some parts that looked like the Yellowstone diatom and some parts that looked like the Niagara diatom. When a form shares features with two different species, it is sometimes called a "transitional form." Not only did the core sample show that a new species had evolved, but it also proved to be the fastest evolution so fully demonstrated in the fossil record.

But how did it happen? Ed wondered what else was changing while the diatom was developing new features. He teamed up with Sherilyn Fritz, a geologist who studies how lakes change through time. Sheri looked at the amount of volcanic ash in the layers and at other fossils. She sent mud to her colleague Cathy Whitlock to look for pollen, the tiny grains that flowering plants produce. Like diatoms, pollen grains fossilize, and they are helpful in tracking changes in plant life, temperature, and rainfall.

Ed and Sheri then analyzed the data and came up with an interesting theory about the mysterious appearance of the Yellowstone diatom. In this activity you will have a chance to explore the world of diatoms, meet the new diatom, *S. yellowstonensis*, learn how to make a core sample, check out Ed and Sheri's data, and see if there is a connection between diatoms and climate change.

PART ONE
Meet the diatoms

Diatoms are dazzlingly beautiful little organisms that live in oceans, lakes, rivers, and puddles. . . just about everywhere you find water. Explore the tiny world of diatoms with a deck of diatom cards.

Work in small groups or with a partner

Each team will need:

- Diatom Fact Cards 1–3 (cut, fold, and tape 12 diatom cards)
- sheet of paper
- tape
- scissors

1 Sizing Up Diatoms

Look at the diatom pictures on the cards. Diatoms come in many sizes. So if diatoms are everywhere, why haven't you ever seen one? Because they are small. How small?

Look at this circle: o. Guess how many diatoms it would take to fill in the circle. (The answer is on the last page of this activity).

2 Discovering Diatom Shapes

Explore how beautiful diatoms are to behold.

a Sort the diatom cards into groups or families in a way that makes sense to you. As you sort the cards, don't forget to read the general diatom facts on the back of the cards.

b What feature or features did your group use to sort?

c Share your sorting with the other groups. Did every group sort the same?

Cut on dashed lines, fold on solid line.

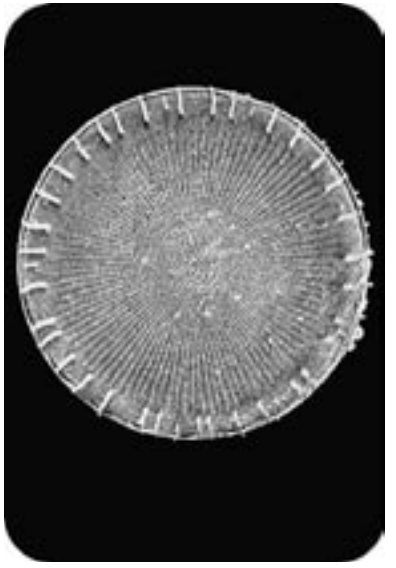
Diatom Fact Cards 1

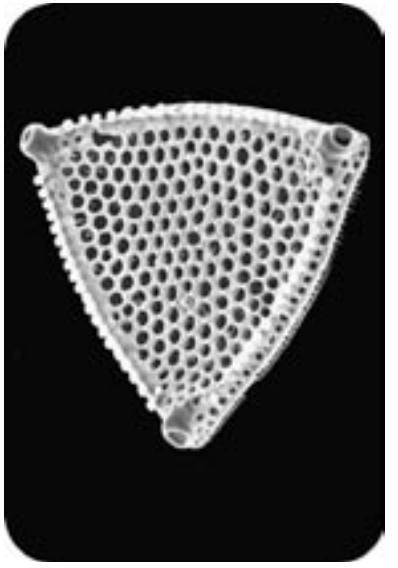
Diatoms are so sensitive to chemical changes in water that scientists use them as markers to track pollution.

Diatoms reproduce by splitting their top and bottom halves apart and growing another half shell.

Diatoms live in both fresh and salt water, rivers, lakes, and ponds. They can be found almost everyplace on Earth that is wet.

Diatoms grow hard, translucent shells of silica that are very much like glass.





Photos courtesy David Harwood and Vladimir Nikolaev.

Cut on dashed lines, fold on solid line.

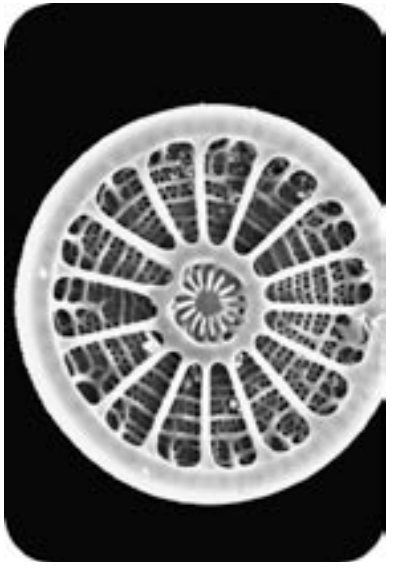
Diatom Fact Cards 2

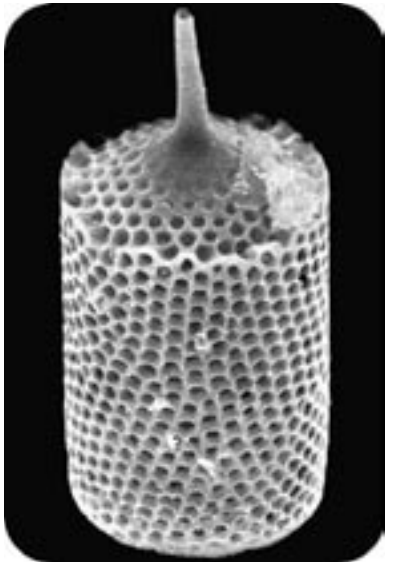
Like land plants, diatoms use sunlight to turn carbon dioxide and water into food and oxygen.

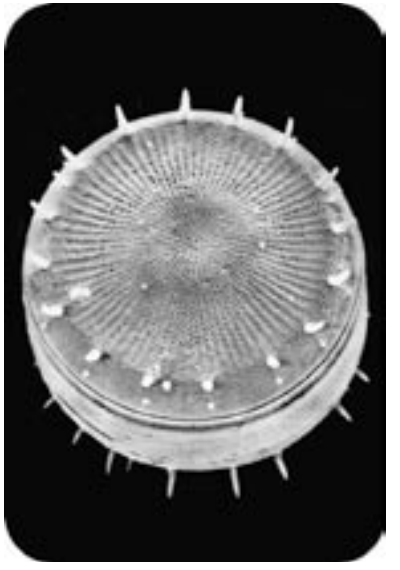
Diatoms have no equipment for moving effectively on their own. They drift about in water or slide on ooze at the bottom of lakes.

Diatomaceous earth (diatom powder) is used in pool filters. The tiny holes in diatom shells make them an excellent filter material.

Small diatoms measure 15–20 micrometers(twice the size of a red blood cell, too small to see). The biggest diatoms measure up to 200 millimeters (as wide as a pencil line).







Photos courtesy David Harwood and Vladimir Nikolaev.

Cut on dashed lines, fold on solid line.

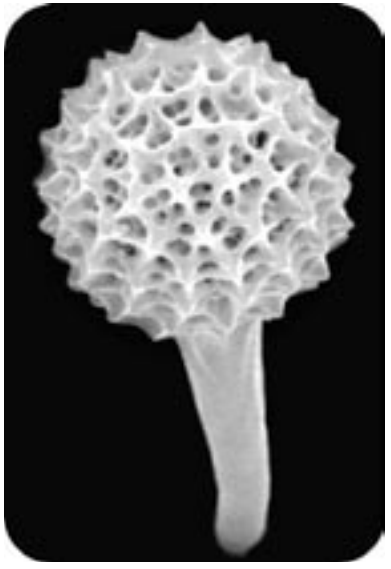
Diatom Fact Cards 3

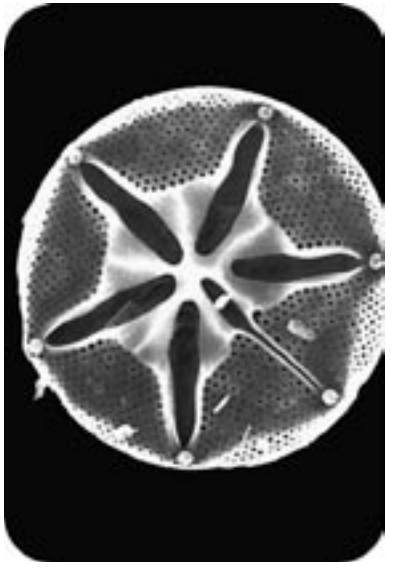
Probably the most important life form on Earth, diatoms are constantly at work turning sunlight into food. They are a basic food for many other animals from tiny shrimp to giant whales.

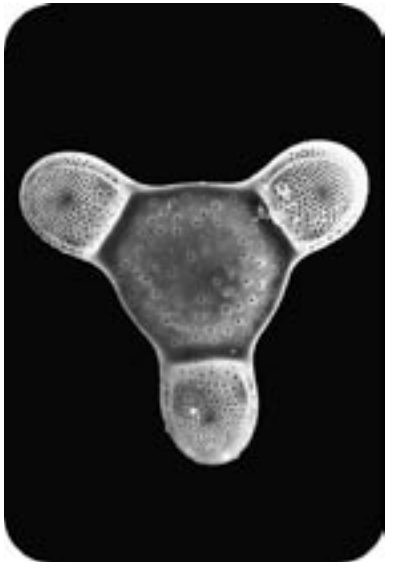
Pond scum is another name for diatoms. The brown slime on stones at the water's edge is very likely a huge population of tiny diatoms.

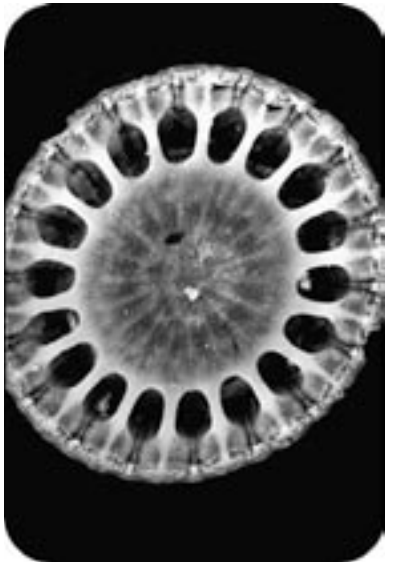
Diatoms are single-celled organisms. There are more than 250,000 species of diatoms. Each one has a unique shape.

Police sometimes use diatoms to help solve crimes. The unique mix of diatoms in a lake or river can pinpoint a water source. This has proved handy in identifying where a victim with lungs full of water originally died.









Photos courtesy David Harwood and Vladimir Nikolaev.

3 Fascinating Facts

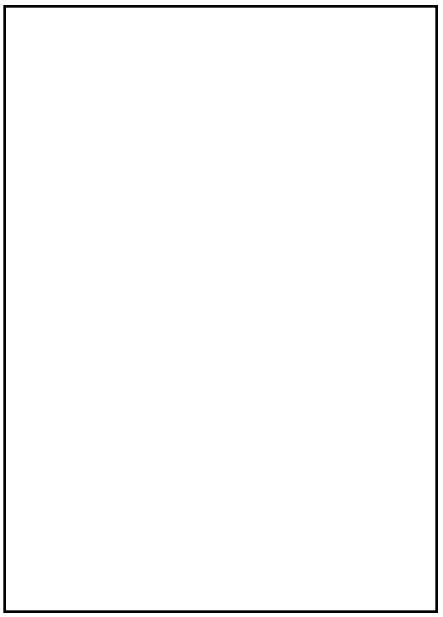
Recall your favorite diatom fact. Write it in the form of a question. Use your question to quiz the rest of the group.

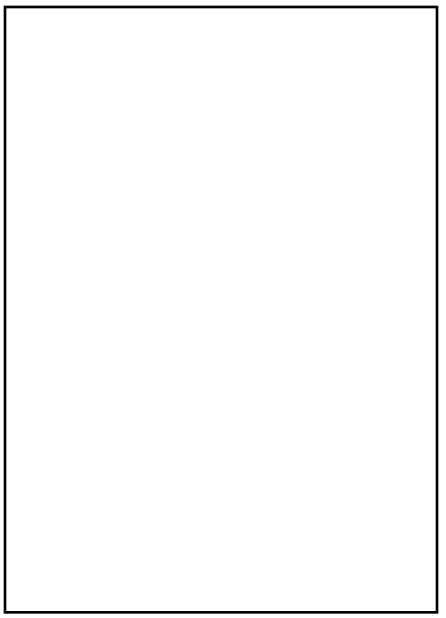
4 Who's Closely Related?

Choose two diatoms that you think are most closely related. Tape them in the boxes below. Why do you think they are closely related?

Discovering Diatom Shapes

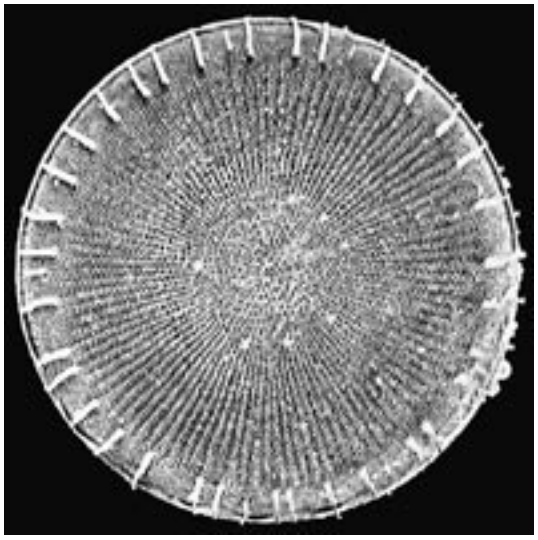
Tape your card choices here



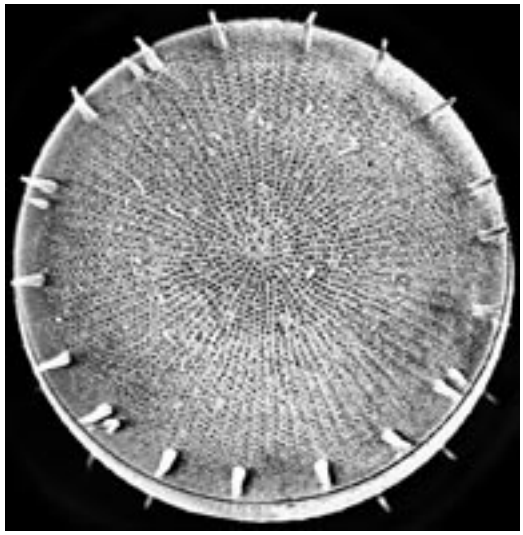


5 Diatom I.D.

The new diatom that Ed and Sheri studied was named *Stephanodiscus yellowstonensis* after the lake it was found in. It is very similar to another species, *Stephanodiscus niagarae,* which is found in neighboring lakes, but not in Yellowstone Lake. Both diatoms can be identified on these scanning electron microscope (SEM) images by their round shape like a bicycle wheel with many thin ridges or "ribs" radiating out from the center.



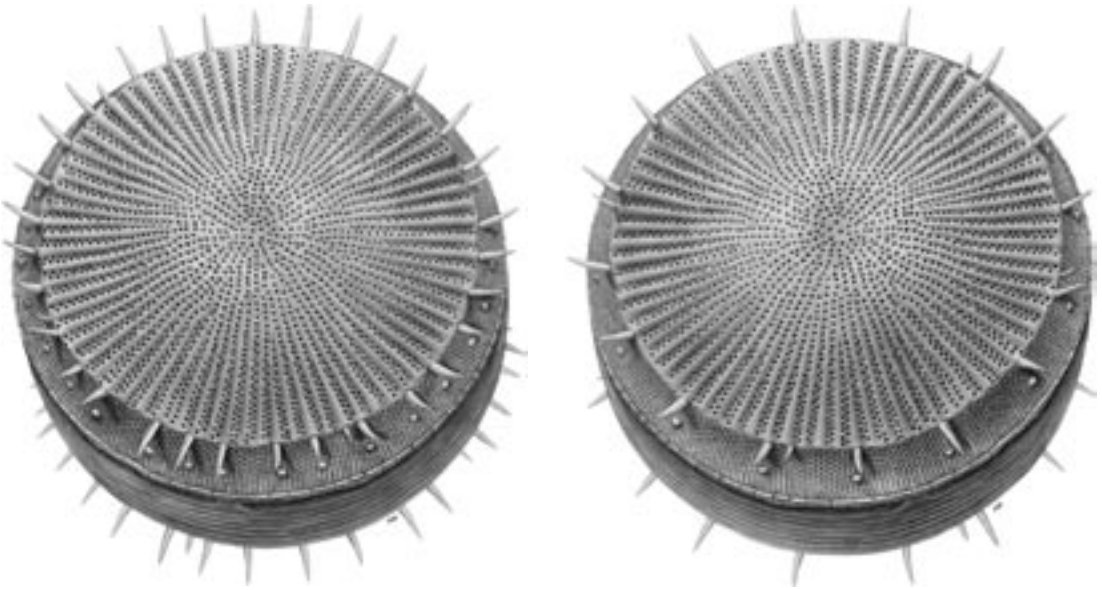
S. niğarae, Photo courtesy Edward Theriot.



S. yellowstonemsis. Photo courtesy Edward Theriot.

6 Consider This

Look at the drawings of the two species of diatom shown below.



How do you know they are different species?

Hint: The experts count the number of "ribs" between the pointy "spines" jutting out from the ends. How many ribs are there for every spine in the Niagara diatom? How many ribs to spines are there in the Yellowstone diatom?

Resources

Selected resources on evolution for middle school teachers and youth leaders

Books About Evolution for Teachers and Youth Leaders

Burne, D. 2002. *Evolution: A beginner's guide to how living things adapt and survive.* New York: Dorling Kindersley.

Charlesworth, B., and D. Charlesworth. 2003. *Evolution: A very short introduction.* Oxford: Oxford University Press.

Gould, S. J., ed. 2001. *The book of life.* New York: W.W. Norton and Company.

Howard, J. 1982. *Darwin: A very short introduction.* Oxford: Oxford University Press.

Mayr, E. 2001. *What evolution is.* New York: Basic Books.

Weiner, J. 1994. *The beak of the finch: A story of evolution in our time.* New York: Vintage Books.

Zimmer, C. 2001. *Evolution, the triumph of an idea.* New York: Harper Collins Publishers.

Activities and Curricula About Evolution

Benz, R. 2000. *Ecology and evolution: Islands of change.* Arlington, VA: NSTA Press.

Lawrence Hall of Science. 2003. *Life through time.* Berkeley: University of California Press.

Stein, S. 1986. *The evolution book.* New York: Workman Publishing.

Resources on Teaching About Evolution

American Association for the Advancement of Science (AAAS). 1993. *Benchmarks for science literacy.* New York: Oxford University Press.

American Association for the Advancement of Science (AAAS). 2001. *Atlas of science literacy.* Washington, DC: American Association for the Advancement of Science.

Beardsley, P. M. 2004. Middle school student learning in evolution: Are current standards achievable? *The American Biology Teacher* 66: 604–612.

Bybee, R. W., ed. 2004. *Evolution in perspective: The science teacher's compendium.* Arlington, VA: NSTA Press.

Griffith, J. A., and S. K. Brem. 2004. Teaching evolutionary biology: Pressures, stress, and coping. *Journal of Research in Science Teaching* 41: 791–809.

National Academy of Sciences (NAS). 1998. *Teaching about evolution and the nature of science.* Washington, DC: National Academy Press.

National Research Council (NRC). 1996. *National science education standards.* Washington, DC: National Academy Press.

National Research Council (NRC). 2000. *Inquiry and the national science education standards: A guide for teaching and learning.* Washington, DC: National Academy Press.

Resources on Learning About Evolution

Bishop, B. A., and C. W. Anderson. 1990. Student conceptions of natural selection and its role in evolution. *Journal of Research in Science Teaching* 27: 415–427.

Brumby, M. N. 1979. Problems in learning the concept of natural selection. *Journal of Biological Education* 13: 119–122.

Clough, E. E., and C. Wood-Robinson. 1985. How secondary students interpret instances of biological adaptation. *Journal of Biological Education* 19: 125–130.

Evans, E. M. 2000. The emergence of beliefs about the origins of species in school-age children. *Merrill-Palmer Quarterly* 46: 221–254.

Evans, E. M. 2001. Cognitive and contextual factors in the emergence of diverse belief systems: Creation versus evolution. *Cognitive Psychology* 42: 217–266.

Lawson, A. E., and W. A. Worsnop. 1992. Learning about evolution and rejecting a belief in special creation: Effects of reflective reasoning skill, prior knowledge, prior belief, and religious commitment. *Journal of Research in Science Teaching* 29: 143–166.

Poling, D. A., and E. M. Evans. 2004. Are dinosaurs the rule or the exception? Developing concepts of death and extinction. *Cognitive Development* 19: 363–383.

Poling, D. A., and E. M. Evans. 2004. Religious belief, scientific expertise, and folk ecology. *Journal of Cognition and Culture: Studies in the Cognitive Anthropology of Science* 4: 485–524.

Resources on Evolution and Creationism

Jackson, D. F., E. C. Doster, L. Meadows, and T. Wood. 1995. Hearts and minds in the science classroom: The education of a confirmed evolutionist. *Journal of Research in Science Teaching* 32: 585–611.

National Academy of Sciences. 1999. *Science and creationism: A view from the National Academy of Sciences.* 2nd ed. Washington, DC: National Academy Press.

Numbers, R. L. 1992. *The creationists: The evolution of scientific creationism.* New York: Knopf.

Scott, E.C. 2005. *Evolution vs. creationism, an introduction.* Berkeley: University of California Press.

Skehan, J. W., and C. E. Nelson. 2000. *The creation controversy and the science classroom.* Arlington, VA: NSTA Press.

Web Resources about Evolution

http://evolution.berkeley.edu
Developed by the UC Berkeley Museum of Paleontology, this site supports a wealth of resources for teachers.

http://explore-evolution.unl.edu
This site provides information about the Explore Evolution project, with links to the museums where the Explore Evolution exhibit galleries are on display.

http://tolweb.org/tree
This site explores the National Science Foundation-funded Tree of Life Project.

www.nabt.org/sup/resources/ask.asp
This National Association of Biology Teachers site provides useful information about the teaching of evolution.

www.ncseweb.org
The home page for the National Center for Science Education, this site is a clearinghouse for information about the teaching of evolution.

www.nsta.org
This site provides information about resources available from the National Science Teachers Association.

www.nap.edu/books/0309053269/html/index.html
This site contains the entire text of the National Science Education Standards of the National Research Council.

www.pbs.org/wgbh/evolution
This PBS site includes video clips, interviews with scientists, and many other resources on evolution.

http://wonderwise.unl.edu
This site presents a series of nine multimedia science kits, each based on the research of a women scientist. These award-winning kits were developed by the same team that created the Explore Evolution project.

About the Authors

Linda Allison is an independent designer of learning experiences. She has created a wide range of educational tools and toys, including books, kits, and electronic media products for clients such as Texas Instruments, the Exploratorium, The Nature Company, Sony, Apple, and IBM. She has been a contributor to numerous award-winning projects, including the *New York Times* best-seller *Blood and Guts: A Working Guide to Your Own Insides.*

Judy Diamond, Ph.D. is the director of the Explore Evolution project and the Wonderwise, Women in Science learning series. Professor and curator at the University of Nebraska State Museum, she is the author with Alan B. Bond of *Kea, Bird of Paradox: The Evolution and Behavior of a New Zealand Parrot,* published by the University of California Press. She is also the author of *Practical Evaluation Guide, Tools for Museums and Other Informal Educational Settings,* published by AltaMira Press.

Sarah Disbrow, Ph.D. is an independent writer and editor of multimedia educational projects, museum exhibits, and trade book publications for Houghton Mifflin, Taunton Press, and Creative Homeowner Press. She is a contributing writer and an editor of the award-winning Wonderwise, Women in Science learning series and the editor of *Healthward Bound, An Owner's Manual for the Human Body,* produced to accompany the PBS program of the same name.

E. Margaret Evans, Ph.D. is a research investigator at the Center for Human Growth and Development at the University of Michigan. The Spencer Foundation and the National Science Foundation have funded her studies on the emergence of evolutionary concepts, including "Cognitive and Contextual Factors in the Emergence of Diverse Belief Systems: Creation Versus Evolution" published in *Cognitive Psychology.* Her dissertation was titled, "God or Darwin? The Development of Beliefs About the Origin of Species."

Carl Zimmer is the former senior editor of *Discover* magazine, a Guggenheim Foundation fellow, and the author of *Evolution, the Triumph of an Idea,* the companion volume to the PBS series broadcast in 2001. His latest book is *Soul Made Flesh: The Discovery of the Brain and How It Changed the World.*

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Index note: Entries beginning with a C indicate information contained in illustration section.