FOREWORD BY **RICHARD DAWKINS**

# ON TEACHING EVOLUTION

EDITED BY
BERTHA VÁZQUEZ

TIES

Teacher Institute for Evolutionary Science

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Bertha Vázquez

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***For every single science teacher who has presented evolution in their classroom for what it is—the awe-inspiring, unifying theme of the life sciences.***

**We invite readers to visit tieseducation.org/book to find all of the videos and resources mentioned throughout this book and to support your local bookstore by purchasing suggested books at bookshop.org/lists/on-teaching-evolution.**

# Contents

***If you want to build a ship, don’t drum up people to collect wood and don’t assign them tasks and work, but rather teach them to long for the endless immensity of the sea.***

Antoine de Saint-Exupéry

# Foreword

*Richard Dawkins, PhD*

"If you can read this, thank a teacher." So runs a favorite T-shirt slogan. This book inspires me to coin a variant: "If you understand why you exist and rejoice in that understanding, thank a science teacher." More specifically, thank a teacher of evolution. It is a remarkable fact that before Darwin and Wallace burst on the scene, humanity had no sensible account of why we exist—what life is all about. Before Darwin's foundational work, people just supinely and incuriously accepted the fact of their own existence. Not to mention the existence of the dazzling riot of life all around them, from green plants to elephants, from ants to the Great Barrier Reef.

Darwin changed all that. Evolution is perhaps the most thrillingly eye-opening subject any student is ever called upon to learn. Yet, as several of these chapters testify, many students have been brought up by their parents to mistrust the subject, uniquely among all topics in science. This has the effect of compelling teachers to exercise extreme sensitivity and cautious diplomacy. Where teachers of other subjects walk with confident steps into the classroom, teachers of evolution walk on eggshells. In their different ways, the authors of this book have risen to the challenge. They have refrained from evasions such as the contemptible resort of a colleague who "avoided the topic altogether, because it wasn't worth the hassle." You might as well avoid verbs when teaching French!

Mention of verbs calls to mind a lovely notion, which I met for the first time in the pages of this book. "Science as a verb." Science as something you do, rather than as a list of facts to be memorized. Many of these chapters tell of highly imaginative lessons designed to inspire the students with hands-on experience, calling upon them to think creatively and ingeniously. Enthusiasm and a sparkling love of their subject are two of the greatest gifts a teacher can bring to the classroom. These qualities are much in evidence in this book, summed up in a memorable phrase from one of the authors. A teacher who is "happy as a clam in an intertidal zone" will excite students to the same happy and productive state.

Returning to the peculiar problem faced by biology teachers, one of our authors correctly said, "I could not possibly imagine how a teacher could educate a student about biology without the unifying, underlying theme of evolution. It ties concepts together in a way that is both simple and wildly complicated. Without this theme, biology would just be a list of random disconnected facts for students to memorize." It has always struck me as odd that textbooks of biology so often relegate evolution to the final chapter. It should, of course, be chapter 1, for none of the other chapters will make any sense without it.

I reluctantly have to confess that I don't think I'd be very good at coping with the active, religiously motivated pushback that these teachers have to face. "Evolution sounds like an interesting theory, but unfortunately, I don't believe in it." This farcical statement from a student, quoted here somewhere, had me reeling. How would I respond to it? You might as well not believe in gravity—in which case my inclination would be to point to an upstairs window and invite the student to jump. Evolution is not only interesting, it's true! As you'd see, if only you'd open your eyes and look at the evidence. Open your mind and think about the evidence; for evidence is, or should be, the only basis for believing in anything. No, I'm afraid I'd be a failure as a teacher of students like that, which makes me respect the long suffering patience of these authors all the more.

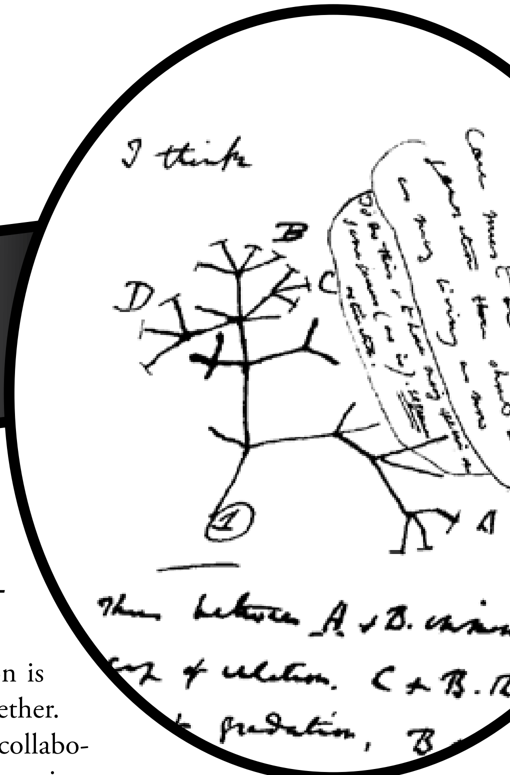
Several chapters allude to the great "only a theory" problem. For years I went along with the standard catechism: science uses "theory" in a different sense from everyday speech where it means "tentative hypothesis." While that is accurate, I'm afraid we are failing to put it across, and the reason is that it actively begs to be misunderstood. "Only a theory" remains undented as the most powerful weapon in the creationist's mendacious armory. I've now switched tactics. Evolution is a fact. It's a fact in the same sense as it's a fact that the planets orbit the sun, and it's every bit as secure.

To be sure, philosophers of science will protest that any fact is only a hypothesis that has so far not been disproved. I like Stephen Gould's retort: "In science, 'fact' can only mean 'confirmed to such a degree that it would be perverse to withhold provisional assent.' I suppose that apples might start to rise tomorrow, but the possibility does not merit equal time in physics classrooms." "Provisional" is an understatement. To deny the fact of evolution in the face of all the evidence (especially molecular evidence) that has been added to Darwin's own massive compilation, would be as perverse as to deny that viruses and bacteria cause disease. We know for a fact that we are cousins of kangaroos, kinkajous, and kookaburras. This "theory" is as likely to be disproved as the theory that apples will rise tomorrow.

Evolution is a fact, but it is still appropriate to use "theory" for natural selection as the dominant driving force in adaptive evolution. There are other driving forces, and they are important: genetic drift, for example. But natural selection remains the only theory ever proposed that is in principle capable of generating functional adaptation. In Darwin's time it was appropriate for him to refer to evolution as a theory in the colloquial sense of hypothesis. You can still call it a theory if you insist, but you'll be widely and mischievously misunderstood. The evidence has now built up beyond the point where to call it anything but a fact would be perverse. Let's all stop calling it a theory and call it what it is. A fact.

I can't name all the individual teachers who have contributed to this splendid book, and I have therefore consciously refrained from naming any of them. But I have to make one exception. Bertha Vázquez is the driving inspiration of the Teacher Institute for Evolutionary Science and of this book. She is a teacher in a million. You have only to see the light of enthusiasm in her eyes, hear the dedication in her voice, to know she would captivate students. But more than that, she works hard behind the scenes to create model lessons and resources not just for her own classes in Florida but for the whole TIES community that she has inspired in every state of the country.

# Introduction




*Bertha Vázquez, MS in Science Education*
*Miami, FL*

Ever since the famous (infamous) John Scopes trial in 1925, teachers have been at the forefront of the fight to have evolution taught properly in America's schools. While some teachers have been literally named in famous court cases, *Epperson v. Arkansas,* for example, most teachers are silent fighters. We never hear from them. And make no mistake, it is a daily challenge to teach the children of this great country one of the cornerstones of scientific thought. While politicians and school board members make it on the news, swinging the evolution education pendulum this way and that, it is our nation's science teachers who spend their days with children, putting in the hours and making a difference. These science teachers can inspire America's future generations and help them understand the importance of evolutionary biology in everything from agriculture and medicine to conservation and human behavior. These foot soldiers introduce students to the "grandeur of this view of life." To see the world through the lens of evolutionary biology is to see the awesome connectedness of all nature. This book provides some of these worthy educators a voice. Each chapter is written by a different teacher, a different voice. Our backgrounds and teaching positions are diverse, but we all share something in common. We care. We understand the impact of what we do every day. All the teachers who have contributed to this book are members of the Teacher Institute for Evolutionary Science (TIES). Our collective passion for the topic of evolution is what brought us together. I thank them all for collaborating on this worthy project.

## History of Evolution Education in the US

The history of evolution education in this country goes back at least a century. Before we hear from the contemporary voices in this book, some background is in order.

*Evolution vs. Creationism* (2004) by Eugenie C. Scott and the fine compilation edited by Andrew J. Petto and Laura R. Godfrey titled *Scientists Confront Creationism: Intelligent Design and Beyond* (2008) are excellent books, thoroughly researched sources detailing the embattled history of evolution education in the United States. Since these in-depth studies on the history of evolution education are readily obtainable, we will only briefly discuss them in this book.

The history of evolution education can be delineated with the following progression during the last ninety years:
**Phase 1—Banning Evolution Education:** The Scopes trial in Tennessee in 1925 led to at least two decades when evolution was hardly mentioned in science textbooks at all. As a matter of fact, evolution curriculum was found in our nation's high school classrooms more often before the Scopes trial than after it. In the 1950s, the space race

with the Soviets sounded the alarm for the importance of science education, including evolution. It wasn't until 1968, however, in the case of *Epperson v. Arkansas,* that it became unlawful to ban the teaching of evolution.

**Phase 2—Equal Time Laws:** The battle against evolution education took on a different theme in the late 1960s and throughout the 1970s. If evolution education could not be banned, its opponents argued for "equal time" for alternative religious explanations of life on Earth. In 1981, Arkansas Act 590 was the first piece of this so-called "equal time" legislation to pass into law. Twenty-seven other states had tried to pass similar legislation before Arkansas without success. In *McLean v. Arkansas Board of Education,* the Arkansas law was challenged and the law was declared unconstitutional. A similar equal time law was passed in Louisiana in 1982. After years of litigation, delays, and appeals, the US Supreme Court finally ruled against equal time for particular religious viewpoints being taught alongside biological evolution in classrooms. (*Edwards v. Aguillard* 1987).

**Phase 3—Repackaging Creationism as Science:** The next phase of the struggle was the fight against the promotion of intelligent design. Intelligent design is creationism offered up as an alternative scientific theory. When speaking or writing about intelligent design, its defenders avoided referring to religion or creationism altogether, just suggesting that evolution was not the only viable scientific explanation for how life has changed over time on our planet was enough. *Kitzmiller v. Dover Area School District* (2005) in Pennsylvania ended this round of the pseudo-controversy with the judgment of Judge John E. Jones, "The citizens of the Dover area were poorly served by the members of the Board who voted for the ID [intelligent design] Policy. It is ironic that several of these individuals, who so staunchly and proudly touted their religious convictions in public, would time and again lie to cover their tracks and disguise the real purpose behind the ID Policy." (2005)

**Phase 4—Academic Freedom:** We now find ourselves in the current stage of the battle, the promotion of "academic freedom" bills. Essentially, these bills allow a teacher to insert creationism into classroom discourse by presenting all the so-called scientific views on a topic. It also allows teachers to discuss the strengths and weaknesses of scientific theories. Of course, teachers do not seem to be exercising their "academic freedom" to debate the merits of whether doctors should wash their hands before surgery, a practice strongly encouraged by the overwhelming evidence behind the germ theory. Nor are they allowing their students to analyze the fine points of the ongoing natural selection debate between Richard Dawkins and E. O. Wilson. Not surprisingly, these bills seem to only address such "controversial" topics such as climate change and the age of Earth.

The first academic freedom bill was introduced in Alabama in 2004. From 2004 to 2015, at least eighty academic freedom bills have been filed in eighteen states. Only three have passed, in Tennessee, Mississippi, and Louisiana. A current, detailed list of these bills can be found under "Academic Freedom" Legislation on the National Center for Science Education webpage. (Chronology of "Academic Freedom" Bills 2013).

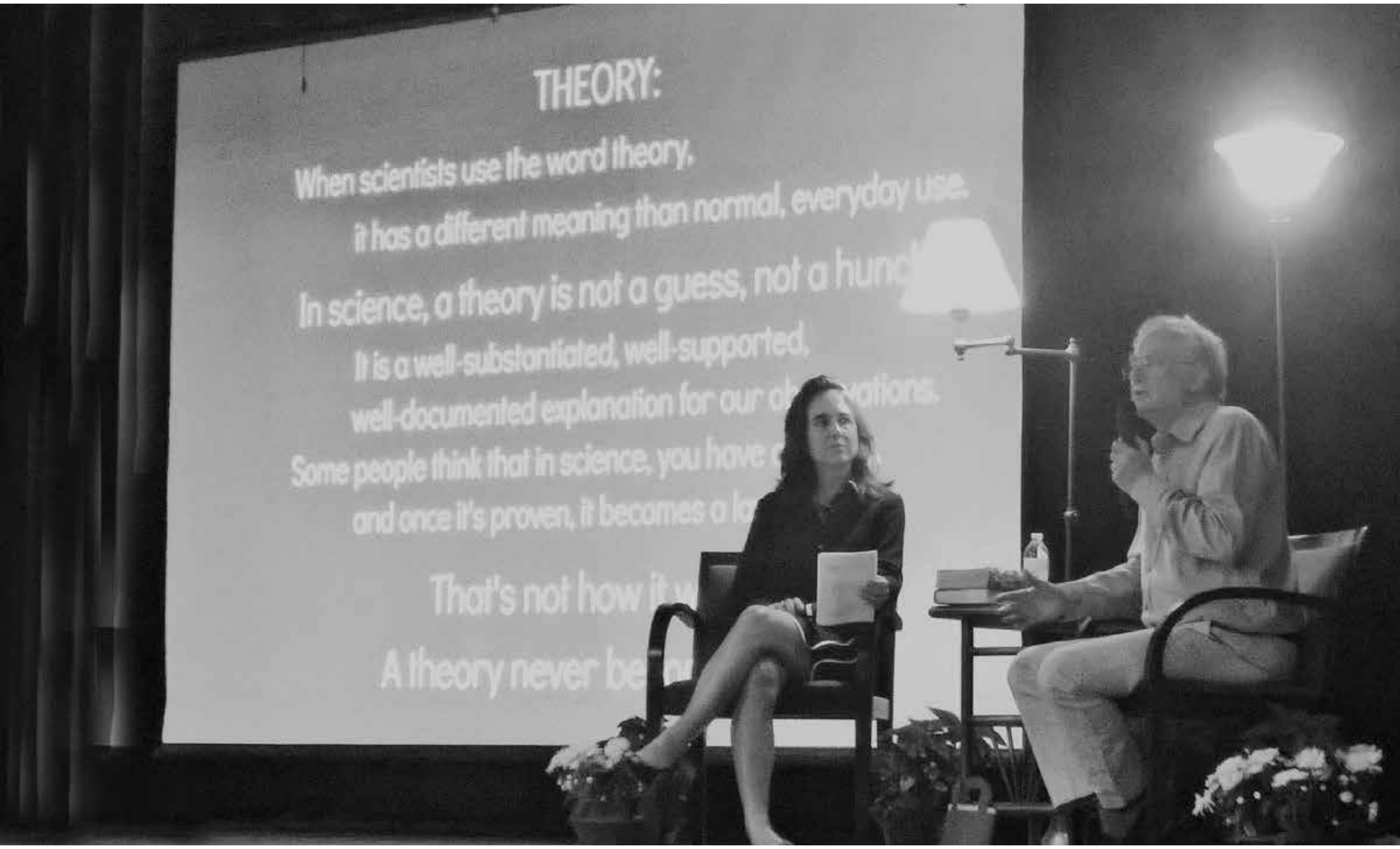
Despite this constant struggle against anti-science forces, current trends in evolution acceptance among young people in the United States are encouraging. For example, the Pew Research Center found that younger adults are more likely than older generations to believe that living things have evolved over time. (Pew Forum 2013)

The cause for this change in evolution acceptance may be an overall loss in religiosity, but perhaps it also is because this younger group of adults has received a better evolution education. "Over the past decade, the concerted efforts of various academic and scientific organizations have led to greater emphasis in textbooks and curricula on the central place of evolution in understanding life" (Carroll 2014).

So, yes, education makes a difference. Yes, the educators who have contributed to this book are on the front lines of this effort. Understanding evolution will be vital as scientific research continues to advance. Let's hear the very personal stories of the teachers who are educating the next generation of Americans.

## History of the Teacher Institute for Evolutionary Science

The purpose of the Teacher Institute for Evolutionary Science is to familiarize interested middle school science teachers with the concepts of natural selection, common ancestry, and diversity for them to confidently cover the




Richard Dawkins speaking to teachers in Miami, Florida in 2014.

topics in their classrooms and fulfill their curriculum requirements. TIES introduces middle school teachers to the most important points of evolution and natural selection with a focus on the amazing advances of genetics. The success of TIES depends upon providing resources that teachers can begin to use immediately. Participating teachers or student teachers leave our workshops with presentation slides, labs, guided reading assignments, an exam, and a valuable resource list for their lesson plans. Our webpage is a one-stop shop for evolution education, and we constantly add new resources on our Facebook page as well.

Let me offer some history on the Teacher Institute for Evolutionary Science and why I decided to focus on middle school science teachers. A middle school science teacher is our system's jack of all trades. It is virtually impossible to become an expert in all our content areas, at least not initially. I have taught everything from meteorology to the laws of motion. I have often stayed a chapter ahead of my students as I learned the difference between an occluded front and a stationary front in the unit on meteorology. And, over the years, it has repeatedly dawned on me that my greatest resource for learning new material and developing effective lesson plans has been my fellow middle school science teachers. We are a talented bunch. My third and fourth years in the classroom were a magical time for me. I team-taught more than sixty sixth graders with one of my school district's shining stars, Mrs. Patricia Soto. Mrs. Soto could captivate a room full of eleven-year olds with any subject matter; her focus was hands-on learning and science inquiry. To this day, I find myself using her ideas and strategies countless times a school year. Years later, I once again found myself team-teaching with an exceptional educator, Mary Martinez. She loved geology and had an extensive rock and mineral collection at her disposal. I learned the wonders of asterism and chatoyancy right alongside the children. If the students only knew that I had no idea what kind of mineral they were showing me, "Hey, Ms. V, is this feldspar?"

"Hmmm," I would answer. "What do you think it is?" As the students studied the mineral, I would walk over to Mary and ask, "Mary, what the heck is this?" When the students were not looking, I would lick the white minerals, knowing I could identify it as halite if it tasted salty.

Besides recognizing the invaluable resources my colleagues provide, I realized we teach best what we know and love best. Our knowledge of a subject leads to our own enthusiasm for it, and this makes a significant difference in our students' learning process. Passion is contagious. Believe me, you want your children learning geology from Ms. Martinez, not me.

Like the countless teachers who have kindly opened their file cabinets and generously offered me lesson plans and lab activities, I wanted to provide something meaningful for my fellow science teachers. Science understanding is constantly expanding. It is very difficult for science teachers to keep up with all the latest research across all the subject areas they teach. I became more interested in providing teachers with professional development opportunities in evolution education specifically after an exciting afternoon with the person many consider today's living representative of Charles Darwin, Richard Dawkins. Professor Dawkins had been invited to be a professor at the University of Miami for one week in the spring of 2013. I was very fortunate to be invited to join the students and faculty of the UM Biology Department for all his small-group lectures.

Now, I must stop and explain that Dawkins has been the greatest intellectual influence in my life. I read his seminal work, *The Selfish Gene*, back when I was in college, and it completely shifted my paradigm. His logic and clarity of thought were very appealing and insightful. I read all his books. And while *The Selfish Gene* was instrumental in making me choose biology as a college major, it was *The Ancestor's Tale* that really captivated me. The thought experiment proposed in this book, of going back in time and tracing our ancestry while meeting our fellow pilgrims along the way, all making our way toward the origin of life itself, was wondrous to me.

Needless to say, it was a thrill to find myself sitting next to him at a small lunch table following one of his lectures. Dawkins was listening intently as one of the biology professors was explaining how evolution could no longer be taught at his son's school. The owner of this local private school had banned teachers from teaching evolution because one parent had complained. We discussed how middle school science teachers in America may not necessarily be well-versed in evolutionary biology and, with this kind of pressure from parents and community leaders, they simply skip over it. Teachers are by nature risk-averse. Would they teach evolution more effectively if they had confidence in the subject and good resources at their disposal?

I went back to my classroom with a mission. Here's a topic that I loved and I had files full of good lessons. Therefore, in 2013, I offered my fellow science teachers a series of workshops on evolution. The highlight of the sessions was a guided discussion of the wonderful book, *Your Inner Fish,* by Neil Shubin.

Dawkins was back in Miami in November 2014 and I shared my experiences with him. He intuitively understood the importance of giving the teachers of this impressionable age group the proper tools to teach evolution. In what was truly a testament to his commitment to science education, he offered to come to my middle school on December 11, 2014, and speak with middle school teachers from all over Miami-Dade County on the Florida State Science Standards on Evolution and Natural Selection. In a two-hour interview, he and I addressed the fundamentals of evolutionary science. Kudos to Miami-Dade County Public Schools for opening the event up to all the school district's science teachers.

Based on the responses from the teachers who attended, the afternoon was a great success. The responses alerted us to the need for middle school science teachers to properly understand evolutionary biology.

This revelation was the cornerstone of the creation of the Teacher Institute for Evolutionary Science (TIES). I was offered the position of director of this new, exciting project. The Richard Dawkins Foundation for Reason

& Science could provide me with the resources to make professional development in evolutionary biology for middle school science teachers an ongoing endeavour.

I decided right away that while the main goal of TIES would be to promote effective evolution education at the middle school level, several other equally significant goals would be addressed. First, our rationale would be to promote the idea that evolutionary biology is awe-inspiring. Teaching evolution enables children to make sense of the world around them. It provides them with an understanding of how all life on Earth is related. Not only is this knowledge exciting, it is the key to many current conservation efforts, agricultural practices, and medical breakthroughs. Understanding evolution is essential if the United States is to continue to be a global leader. I think this spirit is reflected in the chapters which follow.

This was not the only goal I had in mind. TIES would promote teacher leadership. Sadly, the most important decisions in education in the United States often are made by those who aren't teachers. Classroom teachers would present TIES workshops. It takes a teacher to know what another teacher is experiencing daily. I would work with these teacher presenters to compile a list of classroom resources and online activities.

TIES workshops and resources would all be free. TIES materials include presentation slides with active learning ideas, hands-on activities, guided readings, and informative videos. Extremely valuable online resources and recommended readings would also be included. And finally, TIES workshops would not present a single lab activity or hands-on lesson but provide teachers with an entire unit of instruction, from the ice breaker activity to the exam.

TIES would also provide valuable resources of professional support. For example, the National Science Teachers Association (NSTA) has issued an excellent position statement on evolution education. Other sources, such as the National Science Foundation and the comprehensive Understanding Evolution website of the University of California at Berkeley, can become essential when unhappy parents confront science teachers. Teachers can demonstrate that they are not the ones responsible for setting the curriculum for the class and the parents will have to go elsewhere to complain. Having access to these resources takes the teacher "off the hook," so to speak.

Bertha Vázquez with a Silver Fox from the famous domestication experiment in Siberia.

TIES curriculum would highlight modern-day examples of evolution. Sadly, many students are automatically turned off by Darwin's name and anti-evolutionists have deliberately and falsely tried to discredit iconic examples of evolution (Gishlick 2003). A powerful example of the influence TIES can have in a classroom with this goal in mind occurred in April of 2016. I teamed up with a biology professor, Eric von Wettberg, formerly of the Florida International University. One of the participating teachers introduced herself by telling us that she didn't really believe in evolution. She explained that she tells her students that they must study and get a good grade on the test so she can move on. I presented the standard TIES content in the morning, and von Wettberg discussed his research in the afternoon. He explained that 20 percent of the world's population relies on the chick pea for its primary source of protein


Teachers at the inaugural TIES workshop.

and that the global yield of the chickpea crop is declining because of climate change. His lab is attempting to cross the agricultural strains of the chickpea with the much more robust wild strain still found today in southern Turkey and northern Iraq. By introducing genetic variation into the agricultural strain, he is making it a hardier, more resilient crop. In other words, he is using the principles of natural selection to ensure that millions of people continue to have access to an important food source. Our disbelieving teacher left the workshop with a totally different perspective. We can be optimistic that her students will be receiving a very different view of evolution in her classes.

Many TIES workshops, like the one described above, have been the result of helpful collaborations with other community partners, such as zoos, museums, and universities. The first TIES workshop took place thanks to one of these important collaborations with the Phillip and Patricia Frost Museum of Science in Miami. On April 3, 2015, thirty middle school science teachers participated in a daylong workshop that included several guest speakers from the staff of museum scientists. The museum scientists shared research on phylogeny, fossilized amber, the fossil preparation of Xiphactinus (a 475-million-year-old fish), and provided a sneak peek of future museum exhibits. And, as a most special treat, the participants played with a pet silver fox. These foxes are the result of fifty years of artificial selection experiments in Siberia. After allowing only the tamest foxes to breed every generation for fifty years, Russian scientists have created a breed of fox with markedly decreased stress hormone levels. This has created a gentle group of foxes who resemble dogs in both physical and behavioral characteristics.

Since this first workshop more than six years ago, TIES has expanded into all fifty US states. More than ninety classroom teachers have presented more than three hundred workshops varying from one hour to three-day events. Our free resources have been downloaded more than three thousand times. We have also launched the free TIES webinar series, in which biologists and science authors are featured monthly.

Within every experienced classroom teacher is a wealth of pedagogical and content knowledge just waiting to be tapped. We are our own best resources. May you find some excellent ones within these pages.

# 5 Teaching Darwin's Theories

*Robert A. Cooper, MS in Biology*
*Warminster, PA*

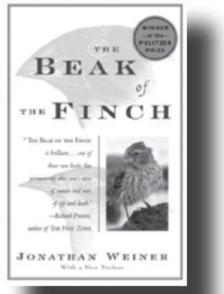
One Sunday evening in December 2016, as I lay drifting off to sleep, I was suddenly jolted out of bed by sharp pains in my lower back, right hip, and running down my right leg. Mild bouts of pain in these areas were no stranger to me. They had occurred chronically over the previous ten or twelve years, but were never as severe as this. I spent the rest of that December night standing at the kitchen sink trying, without success, to find a comfortable position that would relieve the agonizing pain. Early the next morning, my wife took me to the emergency room where the doctor informed me that I had herniated disks in my lower back.

Now that time and surgery have put some distance between the present and that painful experience, I can reflect on the cause of my back problems. The most immediate cause, of course, was pressure on the sciatic nerve caused by bulging cartilage disks between my vertebrae. The disks normally act as shock absorbers, but injury or aging can cause the disks to slip, bulge, or rupture resulting in pressure on the nerves that emerge from the spinal column and pass through narrow passages between the vertebrae. This causes pain, numbness, and tingling. Low back pain is a very common malady. About 80 percent of adults have low back pain at some time in their lives (National Institute of Neurological Disorders and Stroke 2018). But why should low back pain be so common? And why was I afflicted with this pain? I had not done anything strenuous, nor had I injured my back in any way. But age was working against me. My spine had been supporting my body for fifty-nine years, and those years of pressure on the spongy disks that separate the vertebrae caused two of them to bulge and press on nerves.

Why aren't our bodies built better to withstand the pressure our upright posture puts on these disks so they last longer? (Olshansky, Carnes, and Butler 2001). For that matter, why do people get heart disease, diabetes, or cancer? In many respects, the human body appears to be a marvel of design. Your heart beats about one hundred thousand times a day and about thirty-five million times in your lifetime, pumping the blood that transports nutrients and oxygen to your tissues and carrying away metabolic waste. If you've ever seen a patient attached to a heart monitor, you've seen how the slightest body movements cause the heart rate to increase, making adjustments to ensure an adequate supply of oxygen and nutrients to the tissues at all times. Considering the many marvelous features of the human body and contrasting them with the existence of disease prompted physician Randolph Nesse and evolutionary biologist George Williams to ask, "Why, in a body of such exquisite design, are there a thousand flaws and frailties that make us vulnerable to disease?" (Nesse and Williams 1994, 3).

To answer their question with regard to my back problems, we have to adopt an evolutionary perspective. Our bodies are products of evolution, not rational design. Our earliest vertebrate ancestors were fish,

## BOOK RECOMMENDATIONS




For natural selection: an excellent book providing detailed background on Peter and Rosemary Grant's work with Darwin's finches is Jonathan Weiner's *The Beak of the Finch: A Story of Evolution in Our Time* (1994).

For dinosaur-bird transition: *The Rise and the Fall of the Dinosaurs* by paleontologist Steve Brusatte.

whose spine was not subjected to the compression forces our spines must endure (Shubin, 2008). Terrestrial vertebrates inherited their spines from fish, with modifications as species adapted to the conditions found on land, but most of them were quadrupedal and, like fish, their spines were not subjected to the compression forces that ours are. It was our australopithecine ancestors who evolved bidepalism. When they began to walk on two legs, their spines could not be completely refashioned to produce an optimal design for upright walking (Olshansky, Carnes, and Butler 2001).

But issues with our spine that lead to back problems are not the only glitches with which we must contend. Both our bodies and minds are products of the historical process of evolution, and their "design" reflects many constraints and compromises resulting from our evolutionary ancestry (Shubin 2008; Marcus 2008; Lents 2018). Selection only favors modifications to existing structures that are sufficient to allow survival and reproductive success. In other words, evolution tinkers with existing structures to produce satisfactory solutions to problems; it does not redesign from scratch to produce optimal solutions (Jacob, 1977). The prevalence of many human glitches and ailments makes more sense when we consider them from an evolutionary perspective (Nesse and Williams 1994).

## Introducing Evolution

I focus first on natural selection and then consider descent with modification in a later section. Although natural selection seems a simple idea to those who understand it and accept its implications, intuitive concepts and modes of reasoning can make it very difficult for novice learners to develop an accurate understanding of the process (Shtulman 2017). Understanding natural selection requires that students think in ways that are different from the way in which they normally make sense of the world. Children have a natural tendency to explain events in terms of intentions or goals of a central actor, and this tendency can persist into adulthood (Bloom and Weisberg 2007; Sinatra, Brem, and Evans 2008). The application of this intuitive mode of reasoning may cause students to develop misconceptions about processes such as natural selection. One common student misconception is that environmental pressures cause a need for change and all individuals in the population simultaneously respond to this need by adapting, i.e., modifying their features, to survive. This statement reflects goal-oriented thinking and it stems from the fact that students' intuitive theories cause them to focus their attention only on the individual organisms, when they should be dividing their attention between the fate of the individual organisms and the resulting changes in the makeup of the population (Cooper 2017; Lucci and Cooper 2019).

I would choose an introductory activity that enables students to confront this common misconception and begin to develop a more accurate conception of the process. I would have my students observe, analyze, and discuss the histograms shown in figure 1. The histograms illustrate the evolution of beak depth in the medium ground finch (*Geospiza fortis*) under drought conditions on the Galápagos Islands. Guided inquiry instruction in interpreting these histograms will help students develop an understanding of natural selection consistent with what is called for in performance expectations MS-LS4-4 and MS-LS4-6 in the Next Generation Science Standards (NGSS Lead States 2013; See Appendix).

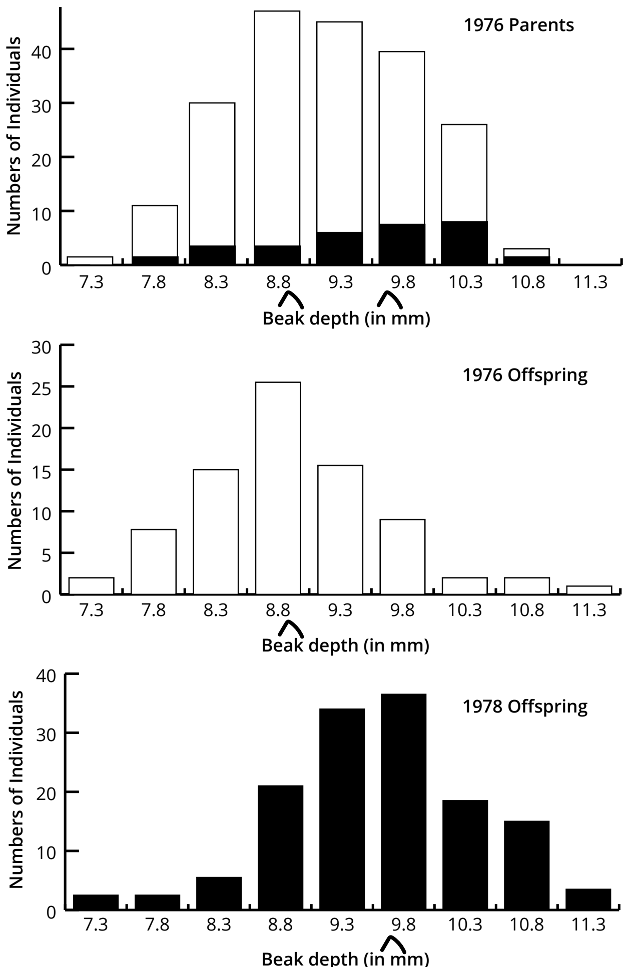



Figure 1: Evolutionary change in beak depth in the population of medium ground finches (*Geospiza fortis*) on the island of Daphne Major (Grant and Grant 2003).

The following story of the 1977 drought and its effect on the medium ground finches serves as an anchoring phenomenon for investigating natural selection. Begin by having students read the following passage:

> Not long ago, if you developed a bacterial infection you could take an antibiotic and know, with confidence, that the medication would cure the infection. But in recent years, many of the bacteria that cause disease have become resistant to antibiotics. Similarly, bed bugs have become resistant to insecticides, and tumors have become resistant to the drugs doctors use to treat cancer. Why is this happening? To understand these issues, it will help to investigate a phenomenon observed in some birds that live on the Galápagos Islands.
>
> In 1973, Peter and Rosemary Grant, two scientists from Princeton University, began a scientific investigation of the birds known as Darwin's finches. Darwin's finches live on the Galápagos Archipelago in the Pacific Ocean six hundred miles west of Ecuador. The Grants chose to work on the island of Daphne Major because of its small size and isolation from human activity. They reasoned that the small size of the island would enable them to capture, band, and measure every individual bird on the island. They measured each bird's weight, wing length, leg length, beak length, beak width, and beak depth. For the first four years, they observed very little change. Then, in 1977 a severe drought that lasted eighteen months struck the island. The Grants observed significant changes in the numbers of individuals of all species living on the island. But most importantly, they documented significant changes in the population of the birds known as medium ground finches (*Geospiza fortis*).
>
> Medium ground finches are seed eaters. Daphne Major is normally populated with a variety of cacti, grasses, and shrubs that all produce seeds that the birds eat. The seeds produced by the various plants have a wide range of sizes and hardness, and the seeds support a population of medium ground finches with a range of beak sizes. But the drought caused a change in the vegetation and a resulting change in the types of seeds available for the finches to eat. As the drought wore on for eighteen months, all of the grasses and shrubs died, leaving only the cacti, and the range of seeds available to eat was more limited. Toward the end of the drought there were only large, hard seeds of the cactus plants left. The scarcity of food, and the fact that there were only very large, hard seeds posed a challenge for the medium ground finches.

## VIDEO RECOMMENDATIONS

Three excellent short films related to Shubin's book, *Your Inner Fish,* that are suitable for the classroom are "Great transitions: The Origin of Tetrapods" (HHMI BioInteractive, 2014b), "Great transitions: The Origin of Birds" (HHMI BioInteractive, 2015b), and "Great transitions: The Origin of Humans" (HHMI BioInteractive, 2014a).

**After students have finishe reading, have them answer the following two questions:**

1. What will happen to the finches with smaller beaks now that there are only large hard seeds to eat? Will they be able to adapt? If so, how will they adapt? Make a prediction and write it in the space below.
2. What other questions do you have about the drought on Daphne Major and its effect on the medium ground finches?

After students respond to the questions, take time to discuss their predictions and any questions they may have about the story. Ask some students to share their prediction with the class. Student predictions can be written on the board, without evaluating them, and revisited in a discussion at the end of the activity. Then provide each student with a copy of the histograms in Figure 1 and explain that they were produced using data collected by Peter and Rosemary Grant. These data will help them test their predictions.

A brief orientation to the histograms will help students get their bearings. Begin by discussing the axes of the histograms to ensure that students understand the variables displayed on each axis. The x axis of each histogram records beak depth, the distance from the top of the beak to the bottom at its greatest extent (See Figure 2). This trait was found to be the most significant of the many traits investigated by the Grants. The y axis of each histogram records the number of birds at each beak depth measured in millimeters (mm).


Figure 2: Beak Depth

Next, discuss with students the shape of the distributions of beak depths. All three are approximately normally distributed (bell curves). The carets beneath the x axes indicate the average beak depths of the distributions. What does this tell you about how the data were generated? Data that follow a normal distribution are generated by a random process. In this case, the normally distributed beak depths are generated by the randomizing processes of meiosis and sexual reproduction. The range of beak depths in the finch population shows the variation in this trait. You can help students understand this by calling their attention to variation in the heights of humans and showing them a histogram of human heights. Remind them that children tend to have heights similar to their parents, and the same is true for the beak depths of the finches. But, in each case there is considerable variation in the population.

Finally, inform students that the white bars in the histogram showing the 1976 parents (top panel) represents the number of birds at each beak depth before the drought occurred, and the black bars show the number of birds remaining at each beak depth after the drought that began in January of 1977 and lasted 18 months. The

1976 parents had an average beak depth of approximately 8.8 mm, and the birds remaining after the drought had an average beak depth of approximately 9.8 mm. The histogram in the middle panel (1976 offspring) displays the distribution of beak depths of the offspring of the 1976 parents produced before the drought, and the histogram in the bottom panel (1978 offspring) shows the distribution of beak depths in the offspring of the 1976 parents that survived the drought. Have students work in small groups of two to three students each to answer the following questions.

## Questions for small group discussion:

**Q1:** There is a considerable difference in the number of birds represented by the white bars and the black bars on the histogram. What happened to the birds from 1976 (white bars) that are not shown in 1977 counts (black bars)?

**Model Response:** Most of the birds on the island in 1976 died as a result of the drought, hence the significantly lower numbers of survivors in 1977 following the drought.

**Note:** Some students may suggest that many of the birds migrated elsewhere to find food. This is unlikely. The distance between Daphne Major and the nearest islands in the archipelago is great enough to make migration very challenging, and birds undernourished because of the drought would not be able to make the trip. Even if they could, the weather conditions causing the drought impacted the entire archipelago, and the archipelago is six hundred miles from the coast of Ecuador, so they could not fly to South America for food.

**Q2:** Could the birds grow larger beaks to survive the drought? If they did, would you expect the pre-drought (white bars) and post-drought (black bars) histograms to look as they do? If they were not able to grow larger beaks, how would the post-drought distribution of beak depths compare to the pre-drought distribution?

**Model Response:** Individual birds cannot grow larger beaks to crack large, hard seeds any more than a slow runner could suddenly develop Olympic-class speed to fulfill a dream of becoming a wide receiver on a professional football team. If all of the birds could "adapt" in this way, then why would any of them die? If individuals could modify their beaks, the number of birds would be the same before and after the drought. All the birds would adapt and survive, and the only change would be that the entire distribution would shift to the right toward a higher average beak depth. The data does not support this claim. Most of the birds died during the drought.

If the birds are not able to grow larger beaks, the histograms would look exactly as they do. Most birds died, but there were differences in terms of the ability to survive during the drought. On the average, birds with larger beaks tended to survive at higher rates than birds with smaller beaks. The group with the highest survival rate had beak depths close to 10.3 mm Approximately one-third of the birds in this class survived, while all other classes had much lower rates of survival. The survivors reproduced and, as a result, the distribution of beak depths shifted toward a higher average beak depth.

**Q3:** Is there evidence that beak depth is an inherited trait? Why is there a difference in the average beak depth of the offspring produced in 1976 and 1978?

**Model Response:** The parents of the offspring produced in 1976 are represented by the white bars in the top panel of figure 1. The parents of the offspring produced in 1978 are survivors of the drought and are represented by the black bars in the top panel of figure 1. In each case, the similarity in the distributions of parents and offspring (with the same average beak depth) suggests that beak depth is inherited. The difference in average beak depth of the offspring produced in 1976 and 1978 was caused by the drought. Birds with smaller beaks died at a higher rate than birds with larger beaks. The survivors, with a larger average beak depth, produced a new generation with a similarly larger average beak depth.

**Q4:** Write a clear and thorough explanation, consistent with the data in figure 1, of how natural selection caused the differences in the distributions of the 1976 parents and the 1977 survivors, and the differences between the 1976 offspring and the 1978 offspring. Be sure to make reference to the data in your response.

**Note:** To scaffold students' efforts to write good explanations for cases where natural selection occurs, I encourage them to structure their explanations using the mnemonic device VISTA (American Museum of Natural History, 2005). This will ensure that they include all of the essential elements of a good explanation. VISTA stands for variation, inheritance, selection, time, and adaptation. This mnemonic captures most of the essential elements of Darwin's theory of natural selection. Applied to the finches during the drought, the mnemonic would produce an explanation that looks something like this:

**Model Response:** All three of the histograms are approximately normally distributed and display a range of VARIATION (V) in beak depth from 7.3 mm to 10.8 mm in the case of the 1976 parents, and a range of 7.3 to 11.8 mm in the cases of the 1976 and 1978 offspring. The distribution of the 1976 offspring resembles that of the 1976 parents and they have the same average. In addition, the distribution of the 1978 offspring resembles that of the 1977 drought survivors and they have the same average. These similarities suggest that beak depth is an INHERITED (I) trait. The drought imposed strong SELECTION (S) on the finches and favored the birds with greater beak depths. A majority of the birds died during the drought, and birds at the lower end of the distribution, with smaller beaks, died at higher rates than those with larger beak depths. Selection caused the average beak depth of the population to shift from approximately 8.8 mm before the drought to approximately 9.8 mm after. This evolutionary change in beak depth took one generation. Evolution by natural selection involves changes in the average traits of a population over TIME (T) (generations). Individuals cannot evolve during their lifetimes. As a result of the change in average beak depth, the population was better ADAPTED (A) to the prevailing environmental conditions immediately following the drought.

## Favorite Investigative Unit or Activity

If I had time enough for just one activity to introduce students to descent with modification and the tree of life, I would introduce these concepts with an activity called "What Did *T. rex* Taste Like?" from the University of California Museum of Paleontology (https://bit.ly/trex-tastelike). The activity introduces students to cladistics, a method used to determine evolutionary relationships between groups of organisms, and classify them based on shared inherited features. In cladistic analysis, biologists use molecular, biochemical, physiological, anatomical, or behavioral features to compare groups of organisms and generate hypothetical evolutionary trees illustrating how the groups are related by evolutionary descent (See appendix for the NGSS Disciplinary Core Idea and the related Performance Expectation MS-LS4-2). Groups of organisms that share a set of features and all derive from a single common ancestor are referred to as clades. Students who complete the *T. rex* activity will gain a better understanding of how to correctly interpret evolutionary trees, or cladograms, and also understand the value of evolutionary trees to biologists.

"What did *T. rex* Taste Like" begins by introducing students to the vast diversity of living things and explains that all species can be traced back through lineages, lines of descent, to a single common ancestor. A comparison is drawn between family trees, or pedigrees, and evolutionary trees. Two children (siblings) from the same family resemble one another because they inherit some common features from their parents, but they also differ from each other and from their parents. Similarly, two closely related species, like coyotes (*Canis latrans*) and wolves (*Canis lupus*), resemble one another because they have inherited some common features from their most recent common ancestor, but they also differ from one another and from their common ancestor. Coyotes and wolves are sibling species. This claim about coyotes and wolves along with its supporting evidence provides a specific example of the general argument that Darwin (1859) makes in the *Origin,* his *One Long Argument* (Mayr 1991). There is no mysterious, supernatural principle guiding evolutionary change. It is simply an extension of the observable facts of biological reproduction and variation extended over long periods of time. In other words, descent with modification.

The main part of the *T. rex* activity introduces students to basic terminology and explains how to correctly read evolutionary trees. Finally, as a culminating special assignment, students are challenged to determine which group in a vertebrate evolutionary tree is most closely related to *T. rex.* As they complete the activity, students learn that birds and theropod dinosaurs, such as *T. rex* and *Velociraptor*, share the most features in common and are therefore close cousins. In fact, birds are considered avian dinosaurs (University of California Museum of Paleontology 2020). Similar to our understanding of the relationship between coyotes and wolves, the logic supporting the claim that birds and dinosaurs are closely related rests upon our understanding of biological reproduction, variation, descent with modification, and the evidence from the fossil record, which demonstrates the anatomical similarities between birds and theropod dinosaurs. Although, a close relationship between birds and theropod dinosaurs was first proposed by Thomas Huxley in the 1860s, it remained controversial until a remarkable collection of fossils was found in Liaoning Province, China, in the mid-1990s. These fossils provide strong evidence supporting the bird-dinosaur relationship. In his book, *The Rise and the Fall of the Dinosaurs,* paleontologist Steve Brusatte explains,

"The Liaoning fossils sealed the deal by verifying how many features are shared uniquely by birds and other theropods: not just feathers, but also wishbones, three fingered hands that fold against the body, and hundreds of other aspects of the skeleton. There are no other groups of animals—living or extinct—that share these things with birds or theropods: this must mean that birds came from theropods. Any other conclusion requires a whole lot of special pleading" (Brusatte 2018, 282).

Although it's possible that the many features uniquely shared by birds and dinosaurs, including complex structures such as feathers, evolved independently more than once, it's not very likely. The simplest explanation is that birds and dinosaurs inherited these shared features from a single common ancestor. In other words, birds and theropod dinosaurs belong in the same clade. Birds are dinosaurs.

After using evidence to determine the relationship between birds and dinosaurs, the *T. rex* activity illustrates for students the value of evolutionary trees to biologists by having them answer questions about soft tissue features, physiology, vision, behavior, and feathers on *T. rex.* No one has ever seen a living *T. rex*, so these questions cannot be answered by observing a *T. rex* directly. All that we have are fossils. But, knowledge of the fact that birds and dinosaurs such as *T. rex* are close relatives enables students to propose likely answers to questions like, "Did *T. rex* have an amniotic egg?"; "Was *T. rex* warm-blooded or cold-blooded?"; "Could *T. rex* have had feathers?"; "Did *T. rex* have color vision?"; "How many chambers were there in *T. rex*'s heart?"; "Did *T. rex* sing to its offspring?" These questions are provided in the teacher's guide as an assessment activity.

After completing the *T. rex* activity, students should watch the short film *The Origin of Species: The Beak of the Finch.* This film serves as an excellent culminating activity that ties together the students' guided analysis of the histograms and the *T. rex* activity. Biologist Sean Carroll, who narrates the film, asks, "So how does one species split into two? A typical scenario is that two populations become separated geographically, and undergo enough change in their respective habitats, that if or when they come into contact again, they do not mate" (HHMI BioInteractive, 2013, time stamp 11:25). Extended over eons, this fundamental process of speciation is responsible for the vast diversity of life we find on Earth.

A fundamental concept that students must understand as an outcome of engaging with the *T. rex* activity is that one does not have to be a time traveler to know that birds originated from the theropod dinosaurs. Scientific knowledge of the past is possible because past events leave behind trace evidence indicating that they occurred (Cooper, 2002, 2004). The ability of scientists to know what happened in the past depends on their ability to find and correctly interpret the trace evidence. Clearly, fossils provide trace evidence that the critters known as theropod dinosaurs once lived on Earth. But just as birds share anatomical features with dinosaurs that show their common ancestry, every living critter currently on Earth also carries trace evidence of its origin, and its kinship with other living things, in its biochemistry, physiology, anatomy, and behavior. The methods of cladistics enable scientists to analyze and interpret that trace evidence. Shared features derived from a common ancestor are called homologies. Living things share homologous features because of the DNA they inherited from ancestors stretching back into the deep recesses of Earth's history. This is why Carroll (2006) referred to DNA as "the ultimate forensic record of evolution."

## Dealing with Misconceptions About Evolutionary Trees

Students' tendency toward goal-oriented thinking also influences their pre-instructional understanding of descent with modification. Rather than viewing evolution as a tree, students see it as a linear process where the goal is to transform primitive ancestral species into more highly evolved forms. Evolution is represented as a ladder of progress, with humans as the inevitable and superior product of the process (Gould, 1989). In images, this view of evolution is typically represented by a horizontal series of primates beginning with a chimpanzee on the left, which is transformed into a series of more human-like ancestors, and finally to a contemporary human. This view is reinforced by a majority of the images students regularly encounter in the wider culture where attempts are made to portray evolution. Images like this are no doubt partly responsible for the recurring question from anti-evolutionists, "If we came from chimpanzees, then why are the chimpanzees still here?" Posing this question for students to consider is a good way to introduce a lesson on descent with modification, and bring students misconceptions forward for examination. Richard Dawkins provides a clear response to the question in a brief video: *Why are There Still Chimpanzees?*. Having students watch this video as one of the culminating activities of a lesson on descent with modification is an effective way to counter one of the most pervasive misconceptions about evolution.

Introducing students to evolutionary trees using the *T. rex* activity is a major step toward improving their understanding of evolution. However, in addition, it is also necessary to directly confront their misconceptions.

Figure 3: A student-constructed evolutionary tree based on the activity described in Halverson (2010).

For example, looking at the evolutionary tree of primates shown in figure 3, students may have the tendency to read left to right across the tips of the branches and maintain the view that evolution is a progressive process leading inevitably toward humans. You can help students confront and dispel this misconception by having them construct their own evolutionary tree similar to the image above using pipe cleaners (Halverson, 2010). With the pipe cleaner tree, students can see that the branches can be rotated around any node and the order of the groups from left to right across the tips is meaningless. All that matters is the branching order, and that is not changed by rotating the nodes.

## Conclusion

Developing an accurate understanding of evolution can be challenging for students. Evolutionary concepts often seem counterintuitive. One of the most difficult misconceptions to overcome is the idea that evolution is a goal-oriented process leading progressively to humans. The activities described here can help students confront and overcome misconceptions related to goal-oriented thinking about natural selection and descent with modification. Students just need a clear demonstration of how their initial understanding fails to adequately explain the phenomenon in question, followed by a clear demonstration of how the scientific theory adequately accounts for the phenomenon.

# Author Biographies

**Nicoline (Nikki) Chambers** has taught high school life science (biology, integrated science, and astrobiology) in southern California since 2003. She holds bachelor's and master's degrees in biology from UCLA, and her teaching credential from Cal State Long Beach. She has held teacher ambassador roles for the UC Museum of Paleontology, the Howard Hughes Medical Institute, NASA's Jet Propulsion Lab, and TIES. She also does curriculum development as a "teacher as researcher" at UC Berkeley and the University of Edinburgh. She loves wondering about how life got to be the way it is (on Earth or any other world), and that every answer leads to ten more questions. Nothing makes her happier than seeing the sparks of curiosity and understanding light up a child's eyes.

**Amanda Clapp** has an MA in anthropology and an MEd in Middle Grades STEM education. She is a National Board Certified teacher and teaches middle school science at The Catamount School, a North Carolina Lab School run by Western Carolina University. The school is operated in cooperation with Jackson County Public Schools, where she has taught in different roles for 16 years. She is a National Geographic Certified Educator and a Kenan Fellow, informing her advocacy for environmental education and equity in North Carolina, and in all schools. As a recipient of the Burroughs Wellcome Fund Career Award for Math and Science Teachers, Amanda is developing a network of partnerships between rural and urban teachers to develop environmental education experiences for their students and strengthen our human understanding through science.

**Kenny Coogan** earned a BS in animal behavior at the University of Buffalo, NY and an MA in global sustainability. He worked in the education departments of zoological facilities for 10 years before becoming a science teacher. He was awarded the Beginning Science Teacher of the Year Award for the State of Florida through the Florida Association of Science Teachers. He has averaged over $10,000 worth of donations for his classroom per year. In his spare time, he is a regular columnist for print magazines such as *Backyard Poultry.* Kenny shares his one-acre permaculture homestead with cats, chickens, ducks, and a 30-year old Moluccan cockatoo named Buddy. His goal is to live off of the land.

**Robert A. Cooper** (@bcooper721) recently retired after thirty-six years of teaching science. For the first five years of his career, he taught life science and physical science at the middle school level. For the remaining thirty-one years he taught biology (AP, Honors, and General) at Pennsbury High School, a large high school in the Philadelphia suburbs, earning National Board Certification in 2009. Robert continues to be an advocate for teaching evolution, as he was throughout his teaching career.

**Chance Duncan** was born and raised in the Arkansas River Valley in Central Arkansas. Chance feels fortunate that he was raised in a rural area and was allowed to explore the fields and woods nearby, getting to know the local ecosystem's flora and fauna. Less lucky for his parents was Chance developing a deep fascination with reptiles, snakes in particular. This fascination led to a tendency to want to share what he found out with his friends and family, so teaching seemed like a natural fit. Chance graduated with his BS in science education from Arkansas Tech University in 2007 and began teaching at a very small, rural school. He moved around to a couple of different districts and began a master's degree program from Montana State University in 2011, completing his MS in science education in 2014. Chance has taught biology in Arkansas for almost a decade and a half and he really can't think of a better career.

**Reginald Finley, Sr.,** is an Atlanta, GA, native. He hosted an online audio program for a decade interviewing experts in diverse scientific fields including Dr. Richard Dawkins. His first experience teaching began as a security trainer, then later as an information technology educator. After earning a bachelor's in human development and a master's in science education, he began tutoring online and volunteered at local science museums. He was eventually afforded an opportunity to work as the director of education and Outreach for Skeleton's Museum in Orlando, Florida. That same year, he was offered a position to work as a biology teacher at Apopka High School. After earning his master's in biology from Clemson, he worked at a private 2nd-12th grade school in Longwood, Florida teaching elementary, middle, and high school students about the wonders of science. He's currently a biology instructor at Valencia College and possesses a PhD in natural science education.

**Kathryn (Katie) Green** earned her PhD in science education and has spent her life in classrooms as a student, a middle school science teacher, an anthropology instructor, and an educational researcher. She also holds undergraduate and Master's degrees in anthropology and became enthralled with hominid evolution in college. Her mission in life is to support teachers in teaching evolution for understanding and acceptance.

**Patti Howell,** EdD, has taught high school science for twenty years in Georgia. Prior to teaching, she was a polyurethane chemist. Her commitment to science education does not stop in the classroom. As District 11 Director for Georgia Science Teachers Association, she is an advocate for teacher training and student learning of science in southwest Georgia. She also works as an educator for Albany's Artesian Alliance, which includes Thronateeska Heritage Center, Chehaw Zoo, and Flint Riverquarium, developing curriculum and delivering programs. In her spare time, she loves traveling and hiking with her husband, Seth. Her favorite role, however, is being Granny to Fiona and Lucas.

**John S. Mead** developed a passion for human origins early in life thanks to books on the topic. John studied at Duke University where he earned his Bachelor and Master of Arts in Teaching (MAT) degrees. Upon graduating in 1990, John found his professional home at the St. Mark's School of Texas where he holds the Eugene McDermott Master Teaching Chair in Science. He has taught most grade levels from 5th to 12th with a focus on the biological sciences and middle school students. In his three decades in the classroom John has worked with a myriad of scientists connected to evolution as well as the study of human origins. He has traveled to all continents except Antarctica following his love of evolution. In recognition of John's work to expand and improve human origins education he has received awards from both local and national groups. He also works with groups including the National Center for Science Education (NCSE), the American Association of Biological Anthropologists (AABA), and TIES because he believes that science literacy matters. You can find John on Twitter at @Evo_Explorer.

**David Mowry** was raised and still lives in Bremen, Ohio. (Don't worry, nobody else knows where that is either). He received a BS in wildlife biology from Ohio University in 2004, immediately after which he worked for one of his professors as a field technician on a mark/recapture mammal study. Starting in 2005, David taught outdoor education in Brinkhaven, Ohio for 4 years. He returned to Ohio University to do graduate work in science education and received his teaching certificate. In 2012, he began working as a science instructor at Mid-East Career and Technology Centers in Zanesville, Ohio, where he is still employed. David currently lives in a former funeral home with his wife, two kids, an incredibly stupid dog, and a bunch of cats that won't leave.

**Blake Touchet** lives in Abbeville, Louisiana with his wife, Chrisanda, and two sons, Luke and Hugo. He has taught middle school, high school, and undergraduate biology and environmental sciences since completing his BS in secondary biology education at the University of Louisiana at Lafayette in 2010. In addition to pursuing advanced degrees in biology (MS from Mississippi State University in 2015) and curriculum leadership (EdD from University of Louisiana at Lafayette in 2021) while teaching, Blake has served as a TIES Teacher Corps member since 2015 and a Teacher Ambassador for the National Center for Science Education since 2017. He has worked on state and district committees for developing curricula, assessments, and mentoring science teachers related to NGSS instructional shifts. His research interests include understanding teacher and administrator knowledge and acceptance of "socially controversial" science topics such as evolution and climate change.

**David Upegui** is a Latino immigrant who found his way out of poverty through science. He currently serves as a science teacher at his alma mater, Central Falls High School (RI) and as an adjunct professor of education. His personal philosophy and inclusive approach to science education have enabled students to become problem-solvers and innovative thinkers. He has a keen ability to engage students in learning, exploring, and contributing to science. He received the NABT's Evolution Education Award (2014) and the Presidential Award for Excellence in Mathematics and Science Teaching in 2019 (2017 cohort). Upegui started, and runs, the school's Science Olympiad team and has contributed to several publications on science education and appropriate pedagogy. He recently completed his doctoral degree in education at the University of RI, focusing on science education and social justice. Reach Upegui on Twitter (@upeguijara).

**Bertha Vázquez** has been teaching middle school science in Miami-Dade County Public Schools for 31 years. A seasoned traveler who has visited all seven continents, where she enjoys introducing the world of nature and science to young, eager minds. An educator with National Board Certification, she is the recipient of several national and local honors, including the 2014 Samsung's $150,000 Solve For Tomorrow Contest and the 2009 Richard C. Bartlett Award for excellence in environmental education. She was Miami-Dade County Public School's Science Teacher of the Year in 1997, 2008, and 2017. Thanks to her work with TIES, she was also the 2017 winner of the National Association of Biology Teachers Evolution Education Award. Bertha has been the director of the Teacher Institute for Evolutionary Science, a project of the Center for Inquiry, since 2015. In her spare time, Bertha is an avid tennis player and bashful ukulele player. She lives in Miami, Florida with her husband, son, and two dogs.