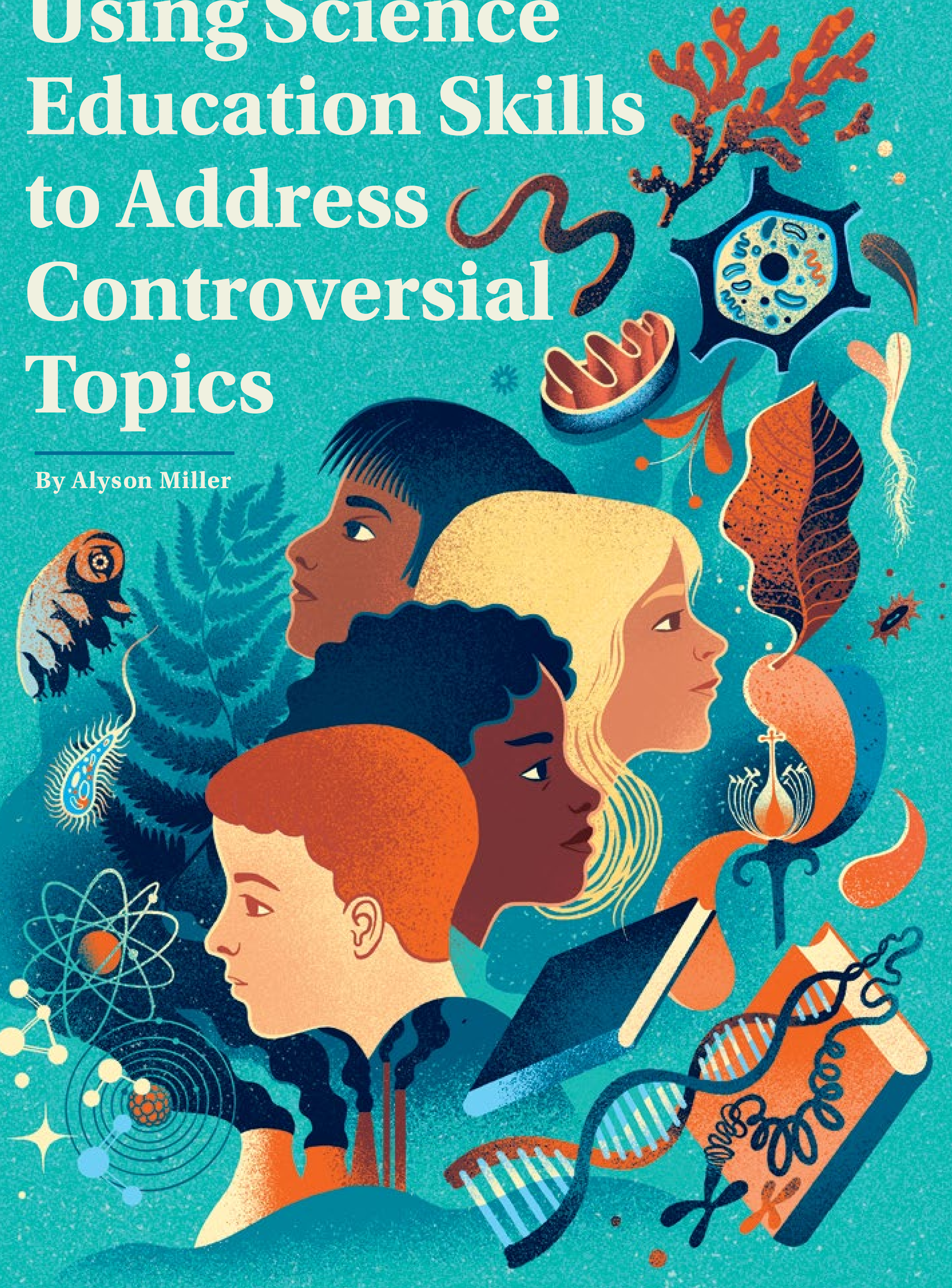
Using Science Education Skills to Address Controversial Topics

By Alyson Miller



"Do they not want us?," I overheard a high school student ask a small group of peers, all recent immigrants to the United States, on the morning after the 2016 presidential election. I rushed to get to the faculty bathroom and back to my classroom in the five-minute break between classes and pretended that I had not heard him, a former student of mine. Normally, he was confident and funny, secure in his popularity among other students, but the catch in his throat bothered me. I should have stopped. I should have said something, anything, to comfort him—but I didn't. I rushed to class.

As soon as I walked into the room, my students pummeled me with questions.

"Who'd you vote for, Miss?"

I'm a white, middle-aged science teacher who wears pearl earrings, Top-Siders, and oversized tortoise-shell glasses. My students—42 percent of whom were enrolled in the free or reduced-price lunch program, 60 percent of them white, 27 percent of them Hispanic or Latinx (and the rest Black, Asian, Pacific Islander, or multiracial), 7 percent with limited English proficiency—couldn't tell from the way I dressed if I had voted for the winner or the loser in that election, and they demanded to know. It was still early in the school year, and they hadn't made up their minds about me. Was I with them or against them?

"I'm not telling you," I said.

"The other teachers told us," one said. "It doesn't matter now if you tell us or not." A wall of male students sat on top of their desks, arms crossed defensively, eyes squinting, practically daring me to give them an answer that they didn't want to hear.

I paused, weighing their argument. Technically, it didn't matter since the election was over and my choice of candidate would not affect their voting behavior or that of their family members. Yet announcing my political views could alienate some students, and that was unacceptable.

"First," I said, "my vote is private. It's personal, and I don't have to tell anyone how I voted."

They didn't move. Maybe a few lips thinned in disapproval.

"Second," I said, "what I believe in more than anything else is equality." I looked down at my desk, away from their eyes. "It's in our Constitution that all men are created equal, and I believe in that more than I believe in anything else." I looked back at them. "That means that if I voted for the winner, and you or your family didn't, then you might perceive me as being a little superior to you. Or if I voted for the loser, and you voted for the winner, then you might think that I'm inferior to you. I'm not telling you who I voted for because you and I are equal, and I'm not going to say anything that would jeopardize that. Period."

It was the only time in my nearly 20 years of teaching that I received a standing ovation, and I instantly had the ear of those students. Later, if I said something that they disagreed with or did not want to believe, they respected me enough to listen. That's a really big thing when it comes to teaching science because we educators are tiptoeing through political and religious minefields as we teach climate change, evolution, and genetic engineering. Some of our students shield themselves against us before they ever hear a word we say. How can we—aside from building on questions that students bring to the classroom during political elections and other major events—use techniques that we've honed as science educators to prevent students from being susceptible to propaganda, pseudoscience, and misinformation? Just as importantly, how can we feel confident enough in our content knowledge to stride boldly into those minefields?

Our common ground is the earth beneath our feet. Every human on the planet has survived an obstacle-filled marathon of epic proportions.

How Science Informs Politics: Diversity Is Necessary for Survival

How many times do we educators hear the mantras "develop relationships with students" or "add a personal touch"? We know we will be better teachers if we connect with our students, but how can we if they come from very different backgrounds than we do? How do we find common ground?

Our common ground is the earth beneath our feet.

Confession time: My passion for equality transcends the US Constitution. In fact, it's more of a mass celebration of survival than a political construct, and it informs the way I interact with everyone—whether or not I agree with their political views. Sharing my mindset has helped students who were dealing with depression, grabbed the attention of reluctant learners, and provided a starting point for political discussions with adult friends outside of the classroom.

So what is it?

It's that every human on the planet today has survived an obstacle-filled marathon of epic proportions. We should be patting each other on the back for making it through the race instead of trying to knock down our fellow competitors—whose help we might need to get us over unknown hurdles in the future.

Early in the school year, I ask my students to think about their parents and grandparents and the wars, poverty, or hardships in faraway lands that they may have experienced. Then I have them think farther back to the last 200 years and of world wars, genocides, pandemics, famines, and droughts. Their families suffered,

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yet in every generation someone had a child who survived long enough to have a child of their own and pass bits of the family DNA into the future.

Again, no matter how bad things got, someone had a child and that child lived and had a child until the child of that child ended up in my classroom. Wow.

But don't stop there. That unbroken chain of children keeps going back through time and then dives into Deep Time.* For millions and maybe even billions of years, a little baton of DNA was passed from one generation to the next. Yes, it changed and mutated as the environment changed, but it kept going through ice ages, tectonic shifts, floods, and *five* mass extinction events. When a meteor wiped out almost all of the dinosaurs,[1] when a mountain range of volcanoes spewed toxic gases into the air and killed nearly everything on the planet, and when oxygen levels spiked or plummeted, someone (or something) had a baby (or the equivalent) that lived, passing on tiny bits of DNA to another generation like little candles of life, until they plopped into the too-small desk chairs in front of me.

As educators, we gain patience, compassion, and respect when we cherish our students as fellow survivors in the struggle for existence.

Students, no matter how easy or how difficult their lives are now, must understand on a deep, visceral level that they have what it takes to overcome adversity. The gene that told their developing bodies to make a right side and a left side goes back 500 million years.[2] Inside their bodies are bits and pieces that survived *T. rexes* and megalodons. DNA is the most amazing molecule in the universe, and it's in every cell in their bodies as a tiny reminder of the thousands of generations that kept going long enough to pass the torch to them.

As educators, we gain patience, compassion, and respect when we cherish our students as fellow survivors in the struggle for existence. Some of them experienced traumas that no one—ever—should endure. Others suffer from mental health issues that jeopardize their chances to lead satisfying lives. Teaching them the history of their body's journey through time can bolster their ability to cope—and ours.

How can we teach this? During my first year of teaching, an administrator wisely advised me to find my voice. Every teacher is different, and no single method works for everyone. I happen to be passionate about Deep Time, so I listen to podcasts such as *The Common Descent Podcast* and *Paleo Nerds* for fun. After giving students time to reflect on the obstacles faced by their immediate ancestors, I assign students to create comic books, to write short stories, or to add panels to a hallway-long geologic timescale that tells fictionalized autobiographies of their DNA. My goal is not to be persnickety about different genes mutating at different frequencies and coming and going from the human genome; instead, my point is to hammer home that life on Earth is very, very old, and that their roots run deep.

Students must also understand the importance of valuing the traits that make us different from each other. When we study ecology, we discuss affiliative behavior and how cooperation helps species survive. We also discuss the importance of genetic diversity and of having the largest possible gene pool in case environmental changes demand a new toolkit. Like deforestation that may wipe out a hidden cure for cancer, "wiping out" people who are different from us could cost us the ability to adapt to a changing environment. Embracing our differences and recognizing each other as fellow shipmates on the journey into the future is not a tree-hugging political statement; it is a mandate for survival.

How Science Leaves Room for Religion: A Search for Natural Causes

Science is the study of the *natural* world.

For years, I thought that was an awkward definition of science left over from the days before Thomas Beddoes invented the term "biology" in 1799, back when many scientists were called "naturalists." Then I finally got the punchline: science is the study of things that can be measured, *natural* things, as opposed to the study of the *super*natural world.

Because one of the goals of science is to figure out causes (independent variables) and their effects (dependent variables), there is no place for supernatural causation in a science classroom. I make it very clear that supernatural beings may be "out there," but science—by definition—limits itself to the natural world.

To my utter shock and delight, I discovered that students quickly grasped the concept of the natural versus the supernatural worlds. Before having this thump-on-the-head insight of natural versus supernatural causation, I didn't know how to respond to students who claimed that something was "God's will." Now, without offending their religious beliefs, engaging in debates about creationism/intelligent design, or trying to explain the First Amendment's Establishment Clause (on the separation of church and state), I simply say, "that may be true, but it assumes

*Deep Time refers to the multibillion-year history of Earth as represented in the geologic time scale and supported by geological and chemical evidence. For more information, see go.aft.org/emc.

supernatural causation, and we can't test that. Alas, in science we are limited to studying the natural world."

Studying the natural world requires collecting measurable data. Those data are plugged into statistical formulas that determine the likelihood of *x* causing *y*. Measuring the natural world often starts with our sense organs, but we've discovered that our senses are limited. For example, we cannot hear the low-frequency calls that elephants use to communicate over long distances. We cannot see the patterns on butterfly wings and flower petals that are only visible under ultraviolet light. We cannot smell the aphrodisiac pheromone (called seducin) released by some male cockroaches. Unlike the duckbill platypus or the great white shark, we cannot feel the electricity given off by distant underwater animals—and unlike some birds, we cannot sense the Earth's magnetic field. Because we cannot sense these events ourselves, can we classify them as part of the natural world?

Yes, because we have developed tools to expand the deficiencies of our sense organs and can reliably measure these events. That is how we are able to tell the story of Earth's history, too—by analyzing chemicals in sediment samples and ice cores, recording types and numbers of fossils, and even breaking open microscopic crystals to measure the components of the atmosphere that were trapped inside them billions of years ago. If the data provided by these tools are reliable—giving similar results under consistent conditions—then we can accept the results as scientific.

What if something is so small or so far away that we can't measure it? Physicists have argued over whether string theory, for example, is a scientific theory or speculative philosophy because there are no tools that can measure anything as small as a subatomic "string."[3] Without measurements, data cannot be collected to support or falsify a theory. In other words, if there is no way to prove it wrong, then it cannot be a scientific theory. But string theory could be proved wrong—or right—*if tools were available* to detect the tiny strings. Today, most scientists agree that because the theory could be tested with as yet unavailable tools, it should be accepted as a scientific theory offering a viable option for reconciling discrepancies between quantum and gravitational physics.

String theory shows us the boundary of science. If we cannot or could not measure or "quantify" something, then it should be discussed in philosophy or religion classes. No hard feelings, no judgments, but science is limited to the natural—not the supernatural—world.

How Science Clarifies Controversies: My Approaches to Three Perennial Challenges

Human-Induced Climate Change

I don't think there's a single topic in science education that makes me fling my head onto my desk and pound my eyeballs the way that climate change does. The graphs and charts and photographs of starving polar bears and numbers and projections overwhelm me. I actually care about it, but … enough already!

That adage "you can't see the forest for the trees" seems to be at work here, so step back and look at the forest, at the big picture. Teaching climate change requires understanding two things: the carbon cycle and the Carboniferous Period of the Paleozoic Era.

Students enjoy learning about the carbon cycle outside on the school grounds, where they can search for specific examples of plants for photosynthesis; insects, birds, or other animals for respiration; and some sort of human activity for the use of fossil fuels, such as cars, weed whackers or leaf blowers in neighboring yards, HVAC equipment, etc. Having them fill out a blank carbon cycle worksheet with examples or create their own from scratch is a fun way to introduce them both to the carbon cycle and to common organisms living near their school.

Back in the classroom, I review or teach the combustion reaction: hydrocarbon + oxygen → heat energy + carbon dioxide + water. Then I ask, "Where did we get those hydrocarbons, also known as fossil fuels?"

Science is the study of things that can be measured, *natural* things, as opposed to the study of the *super*natural world. Students quickly grasp this concept.

Students tend to have the misconception that they are from squished dinosaurs, but at least they know that the hydrocarbons are ancient and nonrenewable. Spiraling back to Deep Time, we journey 300 million years to the Carboniferous (carbon "bearing") Period when most of the coal-based fossil fuels (including some hydrocarbons, such as oils and natural gas) were formed.[4] It was the Age of Amphibians, and enormous salamander-like creatures lived in hot, humid swamps. Conditions for plant life were ideal, but eventually plants die. When dead plants fell into swamps, a lack of oxygen in the mud prevented decomposers from picking apart their atoms and returning the carbon to the air.[†] The carbon that made their bodies was trapped underground. Over millions of years, carbon was removed from the atmosphere much like socks are lost in a dryer and "removed" from the laundry basket. With less carbon in the air to form greenhouse gases (such as carbon dioxide), temperatures cooled, the air became less humid, and swamps dried up. The new conditions marked the end of amphibian dominance and ushered in the Age of Reptiles. (Dinosaurs came later in the Age of Reptiles.)

Hundreds of millions of years passed, and reptiles gave way to birds and mammals—all of us evolving to live in the cool, dry conditions caused from having fewer carbon-based greenhouse gases to act as an atmospheric blanket to keep us warm.

Then humans invented the combustion engine, drilled into the deeply buried old swamps to suck up the trapped carbon, and in less than 300 years pumped tons of it back into the carbon

[†]For more details, see the Smithsonian's "The Age of Oxygen," available at go.aft.org/cgk.

cycle—like suddenly finding all of the lost socks and putting them back into the laundry basket all at once.

Data from the National Oceanic and Atmospheric Administration show that since 1750, the onset of the industrial revolution, levels of carbon dioxide in the air have risen 46 percent.[5] Greenhouse gases trap heat, and carbon dioxide accounts for 80 percent of the heat that is trapped. Earth got very warm very fast. Too much, too soon?

Did the sudden use of fossil hydrocarbons by humans cause the climate to change? Is my laundry basket suddenly too heavy to carry?

Students, like the rest of us, are inundated with information about the effects of climate change on our environments. Scary pictures and talk of the horrors of climate change can be so overwhelming that students—and adults—often either shut down and ignore it or deny that it's true. By offering a simple story that is logical and testable, we educators can provide a starting point for discussions and for research projects on what we can do to help.

By offering a simple, testable story of climate change, we provide a starting point for research on what we can do to help.

Evolutionary Theories

My father was a fundamentalist preacher. My 97-year-old mother still takes offense that anyone would suggest that humans "descended from monkeys." Growing up in a family that found the "E" word more offensive than the "F" word and that rewarded my sister for refusing to listen to the "sacrilegious" ideas espoused by her high school biology teacher, I get it. I know exactly how difficult it is to teach students who actively refuse to participate in lessons in which the "E" word is used.

Being matter-of-fact about *human* evolution through natural selection as a noncontroversial, well-documented theory that has withstood over 150 years of constant challenges should not be difficult. Yet it often is. I use several strategies to avoid threatening the core belief systems of my students and therefore shutting down their learning process.

"Nothing in Biology Makes Sense Except in the Light of Evolution" is the title of a widely read essay by evolutionary biologist Theodosius Dobzhansky.[6] I take this very seriously, using the term "evolution" often. In my classroom, *evolution* is infused in every unit or science standard. There's a lot to say about the evolution of cells, genes, and how organisms interact with each other and their environments, and using the term frequently helps students habituate to it. I've had no pushback, for example, about teaching the endosymbiotic theory that explains how mitochondria became a part of eukaryotic cells.

Knowing that anti-evolutionists come up with new challenges every year, and that teachers are often uncomfortable or lack the content knowledge necessary to respond effectively, I recommend privately watching the Nova documentary *Judgment Day: Intelligent Design on Trial*. Although it is over 10 years old, the documentary is still my go-to resource as a two-hour master class on understanding the nature of science and the legal ramifications of allowing supernatural causation into science classes, and for rebutting false claims of "irreducible complexity" or "it's just a theory." I've rewatched that documentary dozens of times.

At the beginning of the school year, I anonymously survey the students about various topics, including evolution. Some students mention that it goes against their religious beliefs, so later in the year I'll make two offhand comments. The first is that many religions recognize that the human body evolved through natural processes. For example, 25 years ago Pope John Paul II recognized that "the theory of evolution is more than just a hypothesis."[7] These religions claim that the "soul" of man (a supernatural construct, so it's beyond us science people) did not evolve. My second comment is that evolution does not explain how life began. Instead, it explains how organisms changed and diversified into millions of species over time. So far, scientists have been unable to create life from nonlife.

I vividly recall my own days as someone who did not "believe" in evolution and how difficult it was for teachers and friends to chip away at the defensive wall I had built against it. By conceding that we don't know how life began, educators give resistant students the chance to step back, take a breath, and feel as if they have permission to learn about common ancestry because their religious beliefs are not threatened.

While some nonscientists are still arguing whether evolution is real, scientists are not. Scientists are now moving into the third phase of evolutionary thought, while many nonscientists have yet to accept the first one.

Phase I. Darwinian Evolution: The Theory of Evolution Through Natural Selection (Late 1800s)

In *On the Origin of Species*, Charles Darwin claimed that organisms evolve, or change over time, mainly through natural selection (i.e., the struggle to survive).[8] Prior to his work, it was commonly believed that species did not change. He showed that they did change, that modern species descended from common ancestors, and that they were still changing. Gregor Mendel lived at the same time as Darwin and was very familiar with Darwin's work, but Darwin was not aware of Mendel's classic experiments showing how traits were passed on to different generations in plants.[9]

When introducing the evolution unit or standard, I use this simple explanation of evolution as the unintended consequence of three facts:

1. Organisms reproduce (replication).
2. The offspring are not identical (variation).
3. Some offspring pass more of their genes to the next generation than others (selection).[10]

I keep the topic as simple as possible by sticking to Darwin's examples of artificial, natural, and sexual selection.

There are standard examples of evidence for evolution, and I tend to cover them quickly because I prefer devoting more time to recent discoveries. Although I switch up the examples as I find new ones, I generally teach fossil evidence (*Tiktaalik*, *Archaeopteryx*, flatfish), homologous and vestigial structures, and direct evidence of evolution (bacteria, London Tube mosquito, Tennessee cave salamanders).

Phase II. Modern Synthesis: Merger of the Theory of Evolution with Mendelian Genetics (Mid-1900s)

In this phase, the definition of evolution was changed to reflect the role of newly discovered genes in the process of evolution: evolution is the change in the frequency of alleles within a population (i.e., a gene pool). Much of this phase is covered under the topic of genetics or heredity, and it includes how traits are passed to offspring through the process of meiosis. Some variation in traits is due to mutations during DNA replication and to recombination, or crossing over, in homologous chromosomes. For a long time, scientists thought that this was the main source of variation.

Phase III. Evo-Devo: Evolutionary Developmental Biology (Current)

About 15 years ago, the scientist and science educator Sean B. Carroll proposed that evolution of form should be defined as a change in development.[11] Carroll, a leader in the new science of evolutionary developmental (evo-devo) biology, studies how animal bodies form before they are born.

During the 1970s, scientists discounted a lot of DNA as wasteful "junk" because it did not code for proteins. We now know that some of that "junk DNA" is the software for creating our bodies from a single fertilized cell. In terms of biology, this is where the action is. This is where the "variation" part of evolution takes center stage because the genes on this DNA *regulate* other genes, switching them on and off to guide where cells go in an embryo. "Accidentally" leaving them on or off too long creates different body plans, sometimes leading to biodiversity.

Such genetic "toolkits" date back millions of years and are shared by all bilaterally symmetrical animals. For example, they signal cells to form arms and legs at certain places on the embryo. They also direct the building of backbones, chunk by chunk. As Carroll notes, each chunk of backbone takes 20 minutes in zebra fish and two hours in mice. If the "backbone" gene turns on or off at the wrong time, then animals can be born with very long (or very short) backbones. This process can lead to rapid changes in the phenotype and may account for sudden changes in the fossil record, described as "punctuated equilibrium" by paleontologists Niles Eldredge and Stephen Jay Gould.[12] Imagine the diversity of animals that results from different modules of the body being made at different rates!

Or don't merely imagine it. Scientists proved that ancient genes can be turned back on when they grew chicken embryos with teeth and a crocodile-like snout. When human regulatory genes were used in fruit flies, they worked—they turned on the genes that directed the fly to make its body. This indicated a shared ancestry dating back millions of years.

Evo-devo is making rapid advances in understanding both our history and how environmental toxins can cause regulatory gene malfunctions. Discoveries are being made so often that it's difficult to keep up with them. I encourage my students to keep up for me by assigning them research projects to present to the class. They choose their topic, and I help them craft a measurable question to focus their research. Because each student chooses a topic that interests them, it is easy to modify the project for students needing individualized educational plans, English or dual language supports, or other accommodations. For the past few years, questions in evo-devo have topped the list of chosen topics. I'm convinced that the topic is so popular because it ignites their imaginations. As Einstein said, "the most beautiful thing we can experience is the mysterious. It is the source of all true art and science."[13]

By conceding that we don't know how life began, educators help resistant students learn about common ancestry.

Regardless of their academic level, my students work with school librarians for one week to learn how to use scholarly databases and to research a single biology topic in depth. They present the project to the class when we are studying the science standard related to their topics. Other than topics in evo-devo, many students choose topics on bioethics, curing genetic diseases, and how tools like CRISPR work. (Before they present their projects, I review each with the individual students for clarity and accuracy—and so the students are confident about their topic while presenting.) Year after year, I'm impressed with both the students' choices of research questions and the latest information they've discovered. This is where we baby boomers and Generation X'ers step back and applaud what's coming.

Race

Humans have been called "the naked ape."[14] Of the hundreds of primate species alive today, we are the only ones that are not covered in fur. For most of our history, we did not have access to clothes, so our skin was constantly exposed to sunlight—and the amount of sunlight often meant life or death for our children.

If a pregnant woman is exposed to so much ultraviolet light that folic acid molecules break down, then her child may be born with spinal deformities such as spina bifida.

If a child doesn't get enough ultraviolet light to produce vitamin D, then bones cannot absorb calcium and rickets develops; in females, the pelvic bones may become so distorted that childbirth is affected.

Skin color gently changes from dark to light as the intensity of sunlight decreases. Skin color evolved through natural selection. It's that simple.

Reproduction, the number one requirement for evolution to take place, is heavily in play here. Fortunately, our skin can produce a natural sun-blocking pigment—melanin—to block UV rays. So what's the perfect skin color? What is the Goldilocks combination of skin color and sunlight that will provide enough UV rays to prevent rickets while not causing spinal problems?

It depends on where the person lives.

Nina Jablonski, an anthropology professor who studies the evolution of skin pigmentation, revolutionized the way we think about skin color and how it has adapted to different amounts of sunlight.* She calculated the intensity of UV radiation at different latitudes and overlaid those data with measurements of skin color. There was an 86 percent correlation between skin color and UV intensity, which points to a cause-and-effect relationship. Around the equator, where the sunlight is the most intense, skin color is very dark. Moving toward both the north and south poles, where sunlight is least intense, skin color becomes lighter as melanin is lost.[15]

There is no sudden boundary between dark and light; instead, Jablonski refers to the subtle changes in skin color as a "sepia rainbow," with each shade blending into the next one.

Very few students are unmoved when they see Jablonski's maps showing how skin color gently changes from dark to light as the intensity of sunlight decreases. Skin color evolved through natural selection. It's that simple.

Skin color, in fact, evolved independently of other traits that may have been adaptive to life in particular environments. For example, having a narrow nose with a lot of warm blood circulating in it helps people who live in very cold climates heat the air that they are breathing. This is beneficial because cold air irritates the membranes in the nose (and throat). But for people living in warm areas, a narrow nose would be inefficient, without a countervailing benefit. Wide noses allow for more air to be inhaled with less effort than narrow noses, so they are more adaptive for people living in warm conditions.[16] Physical traits of humans showcase the astonishing fitness of our bodies to specific environments.

But, ahem, humans are global movers. What happens when a body that is perfectly adapted to one environment moves to a different latitude?

The good news is that we now know that light-skinned people who live close to the equator require extra folic acid during pregnancy (and sun-blocking agents to prevent skin cancer), and folic acid is added to commercial bread products. Dark-skinned people who live closer to the poles must be monitored for vitamin D deficiencies and affiliated disorders that arise from them. Vitamin D is added to milk products to offset some deficiencies. Living in a northern climate, I encourage all of my students—regardless of where they fit on the sepia rainbow—to monitor their vitamin D levels during their yearly physical exams because even the lightest-skinned people may not be spending enough time outdoors to reap the benefits of sunlight. Being aware of potential health issues from living in areas with different intensities of sunlight is vital for maintaining a high quality of life.

Much like our class discussions of climate change and evolution, our scientific explorations of race are far less charged than such discussions tend to be when they focus on perceptions, cultures, or values. In the few years that I've taught skin color as a trait shaped by the environment, I've yet to have a student who already knew this information. When the conversation is focused on skin color as an adaptive trait, students learn something about themselves, their health risks, and their backgrounds that they didn't already know. Like understanding that their DNA has survived millions of years of catastrophes, learning why their bodies look the way they do makes science education deeply personal.

Open the Door to Wonder

Like being the only naked ape, humans are also the only species that asks "Why?" Many animals have learned *how* to do things—New Caledonian crows figured out how to bend wire to retrieve treats from tubes,[17] many animals know how to use rocks to hammer open hard-shelled food—but we humans are alone on our quest to know *why*.

Young children observe the world around them and ask why the sky is blue, why we can't breathe under water, why we must eat vegetables, and an onslaught of other questions. Some of them are fortunate enough to have extremely patient and knowledge-

*For an overview of Jablonski's findings with links to several resources, including her TED talk, see go.aft.org/i0x.

able adults in their lives who help answer those questions. Many do not. Children may stop asking questions when their curiosity hasn't been rewarded with time and attention. Eventually, they may become disengaged and stop wondering all together.

As science teachers, it's our mission to reengage the wonder. Look at all the cool stuff we have to help us ignite student interest: Deep Time, DNA, evo-devo, skin color, and 30-foot-long amphibians!

It's easy to cut off a student who asks a question that may distract the class from the day's objective. Change your objective. Consider being open to being sidetracked. It's in those moments when an off-the-wall question is thrown at you that you can truly teach the creative nature of science. When a student asked me what would happen if you put a giant MRI machine into orbit over New York City, I dropped everything to step into his imagination and to bring the rest of the class with us. Picturing paper clips flying into the air like upside-down rain and braces being ripped out of their mouths, the students laughed themselves silly and let their imaginations run wild. That's doing science. That's where scientific breakthroughs start. It is in those moments of out-of-the-box thinking that scientists are made.

Why do we teach science if not to open the door to a world of incredulity, of wonder, of knowledge so awe-inspiring that it makes the knees buckle?

Cherishing students as fellow survivors on our rocky planet, celebrating our physical differences because they make our species stronger, and welcoming even the wackiest of questions ignites their interest and acceptance of science. That bodes well for the future. ☐

Endnotes

1. All nonbird dinosaurs died as a result of the meteor, but today's birds are descended from aviary dinosaurs; for more details, see E. Osterloff, "Dinosaurs: How an Asteroid Ended the Age of the Dinosaurs," Natural History Museum.

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3. D. Castelvecchi, "Is String Theory Science?," *Scientific American*, December 23, 2015.

4. For more details, see *Encyclopedia Britannica*, "Accumulation in Reservoir Beds," britannica.com/science/petroleum/Accumulation-in-reservoir-beds.

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12. N. Eldredge and S. Gould, "Punctuated Equilibria: An Alternative to Phyletic Gradualism," in *Models in Paleobiology*, ed. T. Schopf (San Francisco: Freeman, Cooper & Co., 1972), 82–115.

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15. N. Jablonski, *Living Color: The Biological and Social Meaning of Skin Color* (Berkeley: University of California Press, 2014).

16. B. Panko, "How Climate Helped Shape Your Nose," *Smithsonian Magazine*, March 16, 2017.

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Quick Resources for Teachers

Educators connect with students in different ways, and we generously share techniques and lesson plans through social media groups. Sometimes, however, we must distill truckloads of data and subject matter into chunks of "food for thought" that can be easily digested by students. Spending time reading and listening about our favorite topics in science helps transfer some of our passion for learning to our students—and really, that's all we want, right? These are some of my favorite resources.

- Help for guiding discussions can be found through Talk Science, a free professional development program for inquiry-based science instruction: go.aft.org/69w. Especially good advice on how to clarify thinking, rephrase/repeat, and ask for evidence/reasoning is in the tables on pages 9–13 of this study of the effectiveness of the Talk Science approach: go.aft.org/uwk. And the "talk moves" that are the core of the approach are summarized in this checklist: go.aft.org/27l.
- An easy way to drive evidence-based thinking is to use the claims, evidence, reasoning (CER) technique embedded in the Next Generation Science Standard, "Engaging in Argument from Evidence" (see go.aft.org/kin). CER is similar to the talk moves but in written form; it is popular with many teachers because it's easy to apply to most lessons. For more details, see appendix F of the Next Generation Science Standards on "Science and Engineering Practices" at go.aft.org/fhb.
- My favorite podcasts for learning about paleoclimatology, how we know what we know about Deep Time, and fun facts to sprinkle into discussions are:
  - *The Common Descent Podcast*—Hosted by paleontologists David Moscato and Will Harris, this podcast covers a mass extinction in every fifth episode up to episode 100.
  - *Paleo Nerds*—Paleo-obsessed nonscientists Ray Troll and David Strassman interview paleontologists and scientists; they also provide links to engaging resources on their associated website.
- For in-depth understanding of evo-devo, turn to Sean B. Carroll's *Endless Forms Most Beautiful*. The best introduction to the topic is Tim Blais's five-minute video masterpiece, "Evo-Devo ('Despacito' Biology Parody)," available at go.aft.org/tfs. I created a slide presentation that dissects his lyrics frame by frame and use it to drive energetic discussions in class.
- An entire, free curriculum with activities about skin color can be found at Finding Your Roots: The Seedlings, fyrclassroom.org. Developed by Nina Jablonski and Harvard professor Henry Louis Gates Jr., it builds on Gates's "Finding Your Roots" series on PBS, which explores influential people's ancestry. This "Seedlings" version gets young students excited to learn about history, anthropology, genetics, and more as they study their own ancestry.

–A. M.