

An Evolving Controversy

The Struggle to Teach Science in Science Classes



BY MICHAEL BERKMAN AND ERIC PLUTZER

Everyone from President Obama to the average parent seems to agree that the STEM fields—science, technology, engineering, and mathematics—are critical to the nation’s future. But, according to the National Research Council, “too few U.S. workers have strong backgrounds in these fields, and many people lack even fundamental knowledge of them.” The only solution is “a new approach to K-12 science education in the United States.”¹ Last year, the Council took the lead in developing that new approach when it released *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*.

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Like many researchers who are interested in K-12 education, we are overall very pleased with the proposed *Framework* and are eager to see it developed into a new set of standards to guide instruction.* And yet, as political scientists who have studied America’s long-running debate over teaching evolution versus creationism, we bring a unique perspective to the question of implementing any new standards based on the *Framework*. We have not only examined the history of the evolution debate as well as ongoing polls of public opinion, but also conducted a nationally representative survey of how high school biology teachers deal with evolution in the classroom. We see a rough road ahead for teachers.

Our findings are relevant to all K-12 science instruction because the widespread adoption of standards based on the *Framework* will make evolutionary biology much more salient for many teachers who have never before had to teach it. The new *Framework* posits evolution as one of four core ideas in the life sciences. High school teachers will be expected to make evolution central to the biology curriculum. So important is evolution that

ILLUSTRATIONS BY SERGE BLOCH



*That work is under way. To learn more, see www.nextgenscience.org. For a review of the *Framework*, see <http://bit.ly/zDLFC1>.

the *Framework's* building blocks for understanding evolutionary biology begin as soon as children enter school. By the end of second grade, for example, children are supposed to know that “Some kinds of plants and animals that once lived on Earth (e.g., dinosaurs) are no longer found anywhere, although others now living (e.g., lizards) resemble them in some ways.”² Because such early preparation is rare among state standards today, elementary and middle school educators have generally escaped the evolution wars that have ensnared many high school biology teachers; but once standards based on the *Framework* are implemented, these teachers will be expected to provide students with foundational concepts in preparation for studying evolution in some depth during high school.

Moreover, with increasing politicization in our society of astronomy (big bang), health (vaccines), and especially earth science (climate change), controversy could become the new normal for K–12 science study. That would be tragic. Understanding the challenges of teaching evolution has increasing relevance, therefore, across the science curriculum and speaks to more general debates concerning the importance of teachers having deep content knowledge.

Evolution: From Darwin to Today's Consensus

Some teachers, we know, are taken aback by the confidence and apparent brashness of evolution's defenders. The National Academy of Sciences flatly states that “there is no controversy in the scientific community about whether evolution has occurred. On the contrary, the evidence ... is both overwhelming and compelling.”³ More directly, biologist Jerry Coyne's popular book is simply titled *Why Evolution Is True*. Such a confident stance seems to conflict with many nonscientists', including many teachers', understanding of science. Many people think of science as a constant search for new information—and thus *always* subject to revision. Scientists themselves often contribute to this point of view. The American Association for the Advancement of Science's statement on the nature of science,⁴ for example, notes:

Science is a process for producing knowledge. The process depends both on making careful observations of phenomena and on inventing theories for making sense out of those observations. Change in knowledge is inevitable because new observations may challenge prevailing theories. No matter how well one theory explains a set of observations, it is possible that another theory may fit just as well or better, or may fit a still wider range of observations. In science, the testing and improving and occasional discarding of theories, whether new or old, go on all the time. Scientists assume that even if there is no way to secure complete and absolute truth, increasingly accurate approximations can be made to account for the world and how it works.

In this light, some teachers have told us that the emphatic endorsement of evolution and the denial that there are “two sides” can seem immodest or arrogant. Yet such a view fails to appreciate that when a theory survives decades of rigorous testing—as evolution has and its opposing assertions have not—scientists are justified in their high confidence in the theory.

Today, most scientific research is conducted by teams and is supported by research funds obtained through tough competi-

tions subject to peer review. Initial findings from laboratory experiments or from field data are written up as scientific papers. Those papers, too, are subject to peer review; if published in scientific journals, they reflect both the insights of the authors and the confidence that qualified experts have in the methods and logic employed by the investigators. Anonymity allows peer reviewers to raise frank criticisms about findings whenever laboratory procedures, fieldwork, or statistical analyses are questionable. Yet, in spite of the high hurdles to winning research funding and publication, scientists *do* regard published findings as tentative; replication by other laboratories and scientific teams is encouraged and is, in fact, commonplace. It is only after findings have been replicated many, many times that scientists begin to consider them “facts.” Modern evolutionary science rests on a foundation of such facts.

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Indeed, there is no better example of how tentative individual findings can accumulate to highly confident conclusions than the work of Charles Darwin himself. His initial 1859 publication of *On the Origin of Species* went through many printings, editions, and translations; by 1900, most educated people in Europe and North America were familiar with its ideas. Meticulous in its presentation of evidence, written in a style that remains accessible to nonexperts, and rich in its description of the natural world, Darwin's compelling argument about common ancestry offered a theoretical understanding of what naturalists had long observed: dogs resemble wolves, housecats resemble tigers, and apes resemble human beings.

To read *On the Origin of Species* is to be invited inside the mind of a scientist who questions everything, responds fully to actual and anticipated challenges to his conclusions, and understands that his argument will not stand or fall based on any individual finding. Darwin had conceived the basic ideas of common ancestry and natural selection much earlier, but engaged in a 22-year process of accumulating evidence before publishing the work. He sought out and carefully analyzed evidence from mollusks, barnacles, and jellyfish; from ants, wasps, and snakes; from pigeons, mockingbirds, and flightless birds as well as the finches he had observed on the Galápagos Islands. He conducted his own experiments and corresponded with experts worldwide.

Natural selection was the most innovative idea of Darwin's

book and is based on three well-established processes that together lead to changes in populations of organisms. The first is that individuals within a population vary, and the variations can be inherited, so that the individuals of populations are genetically diverse. The second is that, since population growth is restricted by the resource availability in the environment, some individuals within a population are more likely to survive than others. The third idea ties these two together: those individual organisms best able to secure resources or cope with environmental conditions generally are the most likely to survive *and to reproduce*. The traits that favored these individuals will then be passed to their offspring.

Precisely how traits were passed on was not understood by Darwin or his contemporaries. That understanding took decades, beginning with the rediscovery of Gregor Mendel's 19th-century research on heredity: natural selection must act on hereditary determiners (genes) that, individually or in groups, produce traits that are advantageous in a particular ecological setting. The development of population genetics in the first third of the 20th century showed that the natural selection of individual genes could have profound consequences on the distribution of characteristics in populations of a particular species. That is, if the same traits prove favorable for many generations, the distribution of traits in the population as a whole changes.

During the middle third of the 20th century, scientists obtained good evidence that, under certain conditions, natural selection can lead to the emergence of altogether new species. For instance, if members of the same species become physically separated and are subjected to dissimilar environments—on different islands of an archipelago or on opposite sides of a mountain range—they may, over time, display different adaptations and diverge. Given enough time, these adaptive variations can produce organisms no longer able to breed with their distant cousins, and the earlier ancestral species may no longer exist in a recognizable form. "When forces divide a single species into two populations," writes biologist Kenneth Miller, "natural selection will act on each separately, until they have accumulated enough differences that each becomes a separate (and new) species."⁵

Today, evolutionary theory is a framework that integrates Mendel's laws of inheritance, the three principles of natural selection, our understanding of the process of genetic mutation, and population genetics, along with embryology and paleontology. It yields not only powerful explanations for the observed diversity of life, but also a cornucopia of testable hypotheses.

Striking examples of testable hypotheses come from the specialty of systematics—the specialty that produces branching diagrams that show how species are related to one another (phylogenetic trees). For more than a century, these diagrams represented hypotheses based primarily on comparative anatomy

(morphology). Most schoolchildren, using only their powers of observation, come to see that bats are more similar to mice than they are to birds, and that extinct mastodons were more similar to modern elephants than to modern rhinos. Experts in comparative anatomy, of course, can make much finer distinctions using such characteristics as the shape of teeth or the arrangement of bones in joints such as the knee, pelvis, or wrist. These relationships among species, depicted in a tree diagram, imply a series of testable hypotheses.

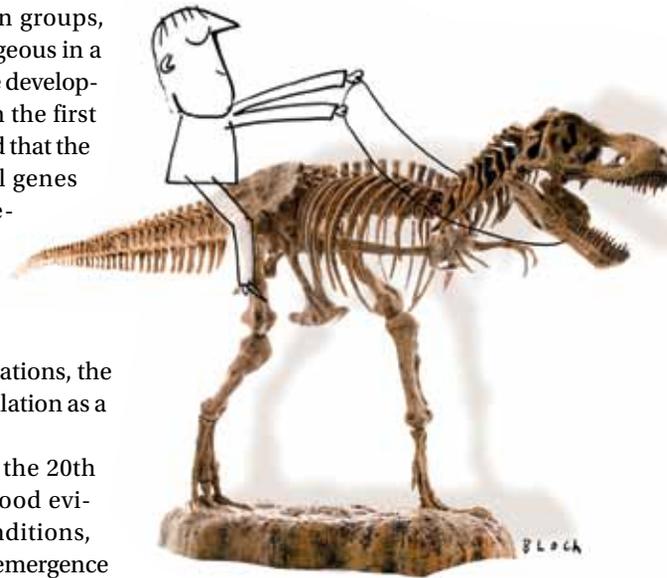
For example, phylogenetic trees in basic textbooks will show that starfish are older (assumed to have arisen earlier) than bony fish, which are in turn older than birds. This is clearly testable: if bony fish were found in older geological strata than starfish, then this portion of the tree diagram would be refuted. But the fact that there are thousands of starfish fossils independently dated to be older than the earliest known fossils of vertebrate fish provides strong evidence for this aspect of the hypothesized evolutionary tree.

Such diagrams also imply that there must have been species that shared features with two or more other kinds of animals. These transitional features must have emerged somewhere in time between the species shown. Hypotheses about *transitional features* can be challenging because not every species lived continuously in conditions favorable for preserving their remains and because transitional forms may have been short-lived. The absence of fossil evidence supporting a transitional feature is not sufficient cause to reject the

hypothesis that these species existed; it may just mean that fossils of transitional species have yet to be discovered or that such fossils never formed. Nevertheless, hypotheses concerning transitional forms represent an important consequence of evolutionary models, and biologists (as well as scientists in many other fields) find it quite exciting when transitional species are discovered.

Consider *Tiktaalik*, a fish, but with the first clear suggestion of wrists, elbows, and a neck. It was discovered in 2004 by biologist Neil Shubin and his colleagues, who had hypothesized that a species showing transitional traits between water and land animals must have lived between 365 and 380 million years ago near both land and water. As told in Shubin's engaging book *Your Inner Fish*,⁶ fossils of *Tiktaalik* were found exactly where expected, by a team painstakingly searching 375-million-year-old rock in the Arctic in an area that at one time contained freshwater streams.

Hypotheses about common ancestry can also be tested through the genetic codes of living animals. By combining modern genomics data with observed rates of genetic mutation, powerful computer programs are able to infer patterns of relationships among species. These programs do not include any information based on analysis of fossils or radioisotope dating; they group species based, for example, on similarities in mitochondrial DNA.



By and large, however, the phylogenetic trees produced in this way are in remarkably close agreement with the traditional evolutionary trees based on observed anatomical traits.

Additional evidence comes from the field of developmental evolutionary biology, which examines embryos that often display vestigial features that do not appear in adults. Contemporary species grouped together in phylogenetic trees are hypothesized to share more developmental similarities than species classified as more distant. Again, many studies of animal embryos have provided independent and convergent evidence supporting these hypotheses.

Although the details are subject to revision based on new and better evidence, the fundamental hypothesis of common ancestry has been verified so many times, by so many independent kinds of experiments spanning different scientific specialties, that *there is no longer serious debate that evolution has occurred*. This justifies confidence in the claim that, as much as any sound scientific statement, evolution is true.

What is often unappreciated—even by many well-educated

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citizens—is that the branching diagrams in high school or college textbooks typically reflect many cycles of hypothesis, experiment, modification of hypothesis, and further experiment. They represent scientists' best current understanding based on multiple and independent tests from the sciences of dating, comparative anatomy, embryology, and genetics. Over time, as knowledge increases and as hypotheses survive rigorous testing, revisions to such diagrams become less frequent and confined to small modifications. As a result, our confidence in these models increases and specific evolutionary paths become accepted as fact.⁷

Public Skepticism of Evolution

By almost any yardstick, evolution science is thriving, and convergent evidence from multiple fields confirms its core ideas. And yet, many Americans continue to reject it. For years, the Gallup polling organization has asked people whether they believe that human beings were created “pretty much in their present form at one time within the last 10,000 years or so.” In a December 2010 poll, 40 percent of Americans chose this creationist response.⁸ Similarly, the 2010 National Science Foundation's Science Literacy surveys found that 39 percent of Americans believe it is *not true* that “Human beings, as we know them today, developed from earlier species of animals.”⁹ Using slightly different wording, a 2007 Pew Forum poll found that 45 percent reject the idea that “Evolution is the best explanation for the origins of human life on earth.”¹⁰

Much of the public also opposes teaching evolution in the classroom. Federal courts have consistently held that states and school boards cannot ban the teaching of evolution or introduce creationism, creation-science, or intelligent design into the public school curriculum. But significant segments of the public do not care. Many do not accept the science, do not want it taught, or prefer approaches that courts have repeatedly rejected as unconstitutional.

For example, a 2005 poll conducted by the Pew Research Center found that 57 percent of the public feels that creationism should be taught “along with” evolution in the public schools, and only 33 percent of the public opposes such a proposal. Indeed, among those opposing the proposal were many who feel it does not go far enough. Once we account for those who would like to see creationism taught “instead of” evolution, this poll suggests that only 22 percent of the public supports teaching evolution and only evolution.¹¹ Other polls using different question wording lead to the same conclusion.¹²

Given that public sentiment is at odds with the nation's scientific organizations and in direct conflict with the rulings of the U.S. Supreme Court, it cannot be easy to be a high school biology teacher. Nor will it be easy for elementary and middle school teachers to meet the *Framework's* expectation that they provide evolution's conceptual building blocks to younger students. Anti-evolution opinion does vary across states and school districts, but even in Massachusetts, the most pro-evolution state in the country, we estimate that less than 50 percent of the public thinks evolution should be taught alone.¹³ In short, polls show that anti-evolution sentiment runs deep in the United States. Further examination shows that anti-evolutionism is closely linked to certain faith traditions—placing evolution squarely in the middle of contemporary culture wars.

The Religious Roots of Anti-Evolutionism

In the mid-1800s, American Evangelicals were riven by divisions based on geography and race. These divisions would soon also extend to theology, leading many southern and midwestern Protestant churches to break away from their northeastern brethren. Their religious principles slowly crystallized and were published in a series of early 20th-century pamphlets called *The Fundamentals* (hence the label Fundamentalist). Among the key elements in Fundamentalist theology was the assertion that the Bible and its creation stories are not only a guide to spiritual life and salvation but also an authoritative textbook of human and natural history—a textbook apparently in conflict with scientific accounts of evolution.¹⁴

By the early 1920s, Fundamentalism was an energetic and thriving religious movement spreading well beyond its southern roots. At the same time, because of the rapid growth of school enrollments, Fundamentalists came to view evolution as an increasingly dangerous idea.¹⁵ If evolution was in conflict with scripture, then its place in the public school curriculum was seen as a threat; this idea soon spread to individuals of other faiths. In a statement intended as the closing argument in the Scopes “monkey trial,” William Jennings Bryan argued in 1925 that in colleges, “Evolution is deadening the spiritual life of a multitude of stu-

dents” and would—if taught in secondary school—“poison the minds of youth” and “destroy ... religious faith.”¹⁶ This idea remains central to anti-evolution politics today.

More than 80 years after Scopes, the legacy of the early Fundamentalists can be seen clearly in contemporary public opinion.¹⁷ Most of the leaders of creationist organizations have come from this faith tradition,¹⁸ and these doctrinally conservative churches are today among the fastest growing in the United States, keeping creationism in the vanguard of anti-evolution politics. It is a tribute to the energy and effectiveness of Fundamentalist clergy and laity that many of their ideas, including biblical inerrancy, are now embraced by individuals in other denominations.¹⁹ Indeed, even though the clergy and leadership in Mainline Protestant and Catholic churches accept evolution, the data show that 35–45 percent of the adherents in these traditions consider evolution false.²⁰ Among the larger American religions, only adherents to Judaism are overwhelmingly accepting of evolution.

While doctrinally conservative churches are highly unified in their opposition to evolution, there is not much consensus in terms of what exactly they stand *for* when it comes to origins. Up until 1968, they fought to keep evolution out of public schools. But after the Supreme Court ruled such bans to be unconstitutional, creationism itself evolved.²¹ For example, a small group of scientists have developed arguments for intelligent design. Intelligent design creationists argue that the odds are close to zero that natural selection and mutation alone could account for complex biological features. Like all estimates of probability, these inferences depend on sets of assumptions, such as the assumption that genetic mutations that confer advantages occur independently, which is simply at odds with mainstream evolutionary biology.²²

Today, we find anti-evolution activists promoting all varieties of creationism; it is opposition to evolution that brings them together. In no small part, this is because the federal courts have made it difficult to introduce any kind of creationism directly into the classroom through state legislation or school board directives. But it also represents a hope that successfully undermining evolution leaves creationism standing as the single and obvious alternative. Eugenie Scott of the National Center for Science Education writes that the idea that evolution is scientifically controversial is the first of the three pillars of modern creationism.²³ The second pillar is the effort to persuade religious Americans that evolution and religion are incompatible, and the third is the idea that “to be fair,” both sides must be taught.

These three pillars are evident in the tactics of creationist activists and politicians. Apparently, they have been successful: we have found that the three pillars of creationism are frequently adopted by high school biology teachers, including many who would not consider themselves members of the anti-evolution movement.

Teaching High School Biology

Clearly, many science teachers work in communities with large numbers of people opposed to evolution. How do teachers navigate such a difficult situation?

To find out, in 2007 we surveyed more than 900 ninth- and



tenth-grade biology teachers.

Our survey is representative of schools across the country, and includes teachers from 49 states and 599 school districts. We asked each teacher about his or her classroom practices, personal beliefs, and pre-service education. And we gave all teachers the opportunity to share their experiences in their own words.²⁴

Our survey allows us to benchmark actual teaching practices to recommendations from the major scientific and science education associations. Of course, the new *Framework* did not exist in 2007, but even then, the National Research Council (NRC), the National Science Teachers Association, and the standards issued by a few states endorsed a rigorous treatment of evolutionary biology. Based on teachers’ answers to our questions, we are able to sort teachers into three broad groups: advocates of evolutionary biology, advocates of creationism, and a group we call the “cautious middle.”

Advocates of Evolutionary Biology

Slightly more than a quarter of the teachers (28 percent) are clear advocates of evolutionary biology. These teachers gave pro-evolution responses to three questions that tap important recommendations from the NRC (and the strongest possible pro-evolution answer to at least two):

1. “When I do teach evolution (including answering student questions), I emphasize the broad consensus that evolution is fact even as scientists disagree about the specific mechanisms through which evolution occurred.” (Agree or strongly agree)
2. “Evolution serves as the unifying theme for the content of the course.” (Agree or strongly agree)
3. “I believe it is possible to offer an excellent general biology course for high school students that includes no mention of Darwin or evolutionary theory.” (Disagree or strongly disagree)

Strong advocates confront each of the three pillars of modern creationism. For one, they do not present evolution as a theory in crisis in any way; they recognize and teach that evolution is an

established scientific finding supported by evidence so overwhelming it has taken on the status of scientific fact. And consistent with the NRC's recommendations (and those of its new *Framework*), they lace evolution throughout their courses. To do this, advocates of evolution spend, on average, 18.3 hours of classroom time on evolution. Their commitment to a thorough treatment of evolution came through in their comments. One Indiana teacher, for example, wrote that "I tell students that I teach evolution as a topic in biology because all other biological functions are based in evolution," while a Pennsylvania teacher stressed how evolution is a unifying theme when she said that "the natural selection process is interjected into almost every topic I cover."

Many of these advocates use evolution to show how science and religion ask different questions and how the aims of each differ, therefore directly countering the idea that evolution is atheistic and incompatible with religious beliefs (the second pillar of creationism). They do this in different ways. Some use evolution as a window into science more generally, while drawing contrasts with religion: "We compare the process, knowledge, societal value and types of questions that are answered by both organized religion and science," wrote one Ohio teacher. "We recognize each serves a different purpose and they do not conflict."

Others, well aware of student sensitivities, confront potential opposition directly and proactively early in the academic year. A teacher from Indiana summed up this approach: "I have been able to present an extensive unit on evolution in an ultra-conservative rural school with minimal negative feedback. I have done this by 1. trying to teach what science is, 2. how science and religion ask different questions and 3. by presenting evidence that science and religion are not in conflict. I do this before exploring the history of evolutionary theory and evidence that evolution has/and is occurring." And still others draw on their personal faith: "My mother is a minister and I'm very familiar with the Bible and have strong religious beliefs myself," an Arizona teacher told us. "I believe this helps me talk with my students about their faith (outside of regular class time) and gives me some extra credibility when I explain that you can believe in your religion AND evolution."

Overall, strong advocates for evolution teach evolution not only as the NRC recommends, but in a way that gives little support to modern creationists. They clearly articulate evolution as an accepted scientific fact. Many contrast it with religion in a way that

suggests to students that one can find ways to reconcile religion and science. And none teach that creationism is an alternative explanation requiring any kind of equal time.

Advocates of Creationism

We classified 13 percent of the teachers as advocates of creationism because they spend at least one hour of class time on intelligent design or creationism and use that time to present it in an affirming manner, as indicated by their agreement with at least *one* of these two questions:

1. "When I do teach about creationism or intelligent design (including answering student questions), I emphasize that this is a valid, scientific alternative to Darwinian explanations for the origin of species."
2. "When I do teach creationism or intelligent design (including answering student questions), I emphasize that many reputable scientists view these as valid alternatives to Darwinian theory."

Given that public sentiment is at odds with scientific organizations and the U.S. Supreme Court, it cannot be easy to be a high school biology teacher.

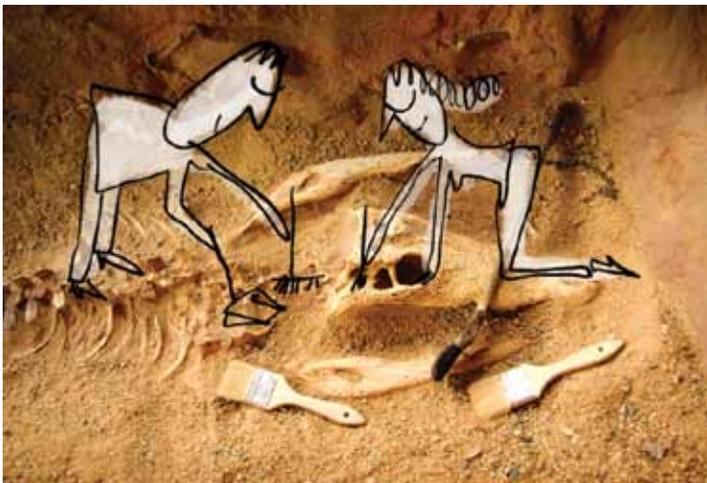
Advocates of creationism both teach some creationism (at least one hour) and minimize instruction in evolution. This is, of course, consistent with the modern creationist objective of undermining evolution. So teachers who advocate creationism spend, on average, only 11.6 classroom hours on evolution, and some spend considerably less. As one Minnesota advocate for creationism explained, "I don't teach the theory of evolution in my life science classes, nor do I teach the Big Bang Theory in my earth science classes. There is just too much science and inquiry that we do not have time to do something that is at best poor science."

An Illinois teacher both undercut evolution and spoke to the modern creationist arguments that evolution and religion are incompatible and that evolution cannot be studied scientifically:

I am always amazed at how evolution and creationism are treated as if they are right or wrong. They are both belief systems that can never be truly or fully proved or discredited as man was not present at the beginning to satisfy his or her curiosity as to the nature of the situation.

Of course, as the discovery of *Tiktaalik* teaches us, science *can* most certainly be used to confirm hypotheses about what hap-

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World-Class Ambitions, Weak Standards

An Excerpt from The State of State Science Standards 2012

Since Sputnik shot into orbit in 1957, Americans have considered science education to be vital to our national security and economic competitiveness. The impact of the Soviet satellite launch on American science classrooms was almost immediate. Shirley Malcom, a leader in the field of science education (and presently head of education programs for the American Association for the Advancement of Science), was a young student in Alabama at the time. She described the swift and palpable shift in the way science was taught:¹

We stopped having throwaway science and started having real science.... All of a sudden everybody was talking about it, and science was above the fold in the newspaper, and my teachers went to institutes and really got us all engaged. It was just a time of incredible intensity and attention to science.

The impact on public opinion was just as

The State of State Science Standards 2012, published by the Thomas B. Fordham Institute, is available at www.edexcellence.net/publications/the-state-of-state-science-standards-2012.html.

profound—and national concern over the quality of American science, and science education, has continued for the past half century. According to a 2011 survey, 74 percent of Americans think STEM (science, technology, engineering, and mathematics) education is “very important.” Only 2 percent say it’s “not too important.”²

Yet this strong conviction has not translated into strong science achievement. The 2009 National Assessment of Educational Progress (NAEP) found barely one-third of fourth-graders in the United States at or above the “proficient” level in science, with those proportions slipping to 30 percent in eighth grade and a woeful 21 percent in twelfth grade.³

Why is this? How can it be that, for more than five decades, Americans have voiced so much concern about science education yet made so little progress in delivering it? There are, of course, multiple explanations, starting with the blunt fact that few states and communities have taken concrete action to build world-class science programs into their primary and secondary schools. Without such programs in place to deliver the goods, our Sputnik-induced anxieties remain fully justified some 55 years later.

A solid science education program begins by clearly establishing what well-educated youngsters need to learn about this multifaceted domain of human knowledge.

Here, the first crucial step is setting clear academic standards for the schools—standards that not only articulate the critical science content students need to learn, but that also properly sequence and prioritize that content. In the light of such standards, teachers at each grade level can clearly see where they should focus their time and attention to ensure that their pupils are on track toward college and career readiness. That doesn’t mean it will happen, of course. As we at the Thomas B. Fordham Institute have repeatedly noted, standards alone cannot drive outstanding achievement. But they are a necessary starting point. They are the score for conductors, musicians, instrument makers, and more. They are the foundation upon which rigorous curricula and instructional materials and assessments are built. They are the template for preparing science teachers for our classrooms.

Fordham has a long-standing interest in science standards and a history of reviewing them with care and rigor. We published our first analysis of state science standards in 1998 and a follow-up review in 2005. Unfortunately, the findings from both evaluations were not good. In 1998, just 36 states had even set standards for science, and only 13 of those earned grades from our reviewers in the A or B range. By 2005, though every state except Iowa had



Undermining Evolution

Where State Standards Go Wrong

According to *The State of State Science Standards 2012*, four problems were found frequently among the mediocre to poor standards: *undermining evolution, including vague standards, failing to integrate inquiry skills with content, and avoiding mathematical formulae and equations.* To complement the main article’s study of how high school biology teachers approach evolution (see page 12), the following is an updated version of the report’s discussion of how evolution is undermined.

—EDITORS

“Nothing in biology makes sense except in the light of evolution.” So wrote famed biologist Theodosius Dobzhansky in 1973.¹ And so it is today. Yet controversy continues to envelop the teaching of evolution in American schools. One wonders, indeed, how much progress we’ve made in this realm since the Scopes trial in 1925. Six years ago, our science reviewers noted:²

The attack on evolution is unabated [since 2000], and Darwin’s critics have evolved a more subtle, more dangerous approach. A decade ago, the anti-evolution movement ... argued vigorously

for explicit teaching of the evidence for intelligent design....

The claim now is that evidence against “Darwinism” exists, that curriculum-makers should include it as an exercise in critical thinking, and that “freedom of speech” or “fairness” requires that they do so. The hidden agenda is to introduce doubt—any possible doubt—about evolution at the critical early stage of introduction to the relevant science.

While many states are handling evolution better today than in the past, anti-evolution pressures continue to threaten state science standards. In April 2012, for example, Tennessee passed a law that enables teachers to bring anti-evolution materials into the classroom without being challenged by administrators. This law is similar to the Science Education Act passed in June 2008 in Louisiana, which is ostensibly an “academic freedoms act” meant to give teachers and students legal cover to debate the merits and veracity of scientific theories. In practice, such measures push a pro-creationist agenda—and give cover to those looking to teach intelligent design creationism. Though both acts are freestanding statutes with no

articulated K–12 science standards, the results were equally disheartening: just 19 earned honors grades, and the overall average was barely a C.

This, our third review, provides analyses of the K–12 science standards currently in place in all 50 states and the District of Columbia, as well as the framework that undergirds the NAEP science assessment. The results of this rigorous analysis paint a fresh—but still bleak—picture. A majority of the states’ standards remain mediocre to awful. In fact, the average grade across all

assessment framework. And seven states earn grades in the B range. But this also means that just 13 jurisdictions—barely 25 percent, and fewer than in 2005—earn a B or better for setting appropriately clear, rigorous, and specific standards.

Of course, as one of our reviewers noted in 1998:

When it comes to academic standards ... even a “B” ought not be deemed satisfactory. In a properly organized education system, standards drive

academic achievement. Several states with exemplary science standards still aren’t serious about setting high proficiency bars on their assessments. Others don’t hold students (or their teachers) properly accountable for learning (or successfully imparting) important content. And still others haven’t provided (or directed teachers to) the curricular and instructional resources that teachers need to drive achievement. But, while standards alone won’t drive achievement, they are an important place to start.

Of the 44 jurisdictions that have revised, replaced, or created their science standards since our 2005 analysis, 11 have shown some improvement, and some of that improvement has been dramatic. Kansas, for example, moved from an F to a B, and Arkansas moved from a D to a B. The District of Columbia rose from a mediocre C in our last analysis to a best-in-class A this time.

By contrast, 16 states managed to make their standards worse since 2005. In fact, five of them—Colorado, New Jersey, North Carolina, Tennessee, and West Virginia—dropped from Bs to Ds.

Note, however, that our criteria have changed since 2005. Therefore, changes in a state’s grade could be due to changes in the quality of the standards, changes in our criteria, or both.* On balance, the combination of improvements and worsenings had little impact on our national average. □

(Endnotes on page 40)

*For more information on our grading metric, see Appendix A of the report.

A majority of the states’ science standards remain mediocre to awful. In fact, the average grade across all states is a low C.

states is—once again—a thoroughly undistinguished C. (In fact, it’s a low C.) In 27 jurisdictions, the science standards earn a D or below. Yet this very weakness in what states expect of their schools, teachers, and students in science suggests that a purposeful focus on improving—or replacing—today’s standards could be a key part of a comprehensive effort to boost science performance.

Two jurisdictions—California and the District of Columbia—have standards strong enough to earn straight As from our reviewers. Four other states—Indiana, Massachusetts, South Carolina, and Virginia—earn A-minuses, as does the NAEP

everything else. If they are only “pretty good,” then “pretty good” is the best the system is apt to produce by way of student learning. No state should be satisfied with such a result. Hence, no state should be satisfied with less than world-class standards in a core academic subject such as science.

States looking to improve their standards, however, need not start from scratch. They can look to places like California and the District of Columbia, and also to the NAEP assessment framework, for models of excellence.

Let us repeat that even the finest of standards alone will never yield outstanding

direct link to the states’ academic standards, they do damage by allowing for the introduction of creationist teaching supplements—thereby affecting classroom instruction.³

Tennessee and Louisiana are not the only states that have tried to undermine the teaching of evolution through legislation. In 2011 alone, anti-evolution bills were introduced in seven state legislatures.⁴

Of course, most anti-evolution efforts are aimed more directly at the standards themselves. And these tactics are far more subtle than they once were. Missouri, for example, has asterisked all “controversial” evolution content in the standards and relegated it to a voluntary curriculum that will not be assessed. (Sadly, this marks a step back from that state’s coverage of evolution in 2005.) Tennessee includes evolution only in an elective high school course (not the basic high school biology course). And Maryland includes evolution content in its standards but explicitly excludes crucial points from its state assessment.

Other states have undermined the teaching of evolution by singling it out as somehow not quite as “scientific” as other concepts of similar breadth. A common technique—used to a greater or lesser extent by Colorado, Missouri, Montana, and West Virginia—is to direct students to study its “strengths and weaknesses.”

Far too often, important evolution content is included, but minimally. Some states mention evolution just once in their standards and never revisit it. Others—including Indiana, Iowa, Kansas, Kentucky, Michigan, and Nebraska—unnecessarily delay it until high school.

Even some of the nation’s best standards subtly undermine the teaching of evolution. In California, for example, students are told to “understand science, not necessarily [to] accept everything taught.” In New York, students learn that “according to many scientists, biological evolution occurs through natural selection.” (This is not according to “many” but, in fact, all true scientists.)

Finally, conspicuously missing from the vast majority of states’ standards is mention of human evolution—implying that elements of biological evolution don’t pertain to human life. This marks a subtle but important victory for creationists: even states with thorough and appropriate coverage of evolution (e.g., Massachusetts, Utah, and Washington) shy away from linking the controversial term with ourselves. Only four states—Florida, New Hampshire, Iowa, and Rhode Island—openly embrace human evolution in their current science standards. (Pennsylvania, which referenced human evolution in its previous standards, has omitted it from the more recent version.) □

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pened in the past. By saying that a scientific discipline is a “belief system,” teachers retreat from the idea that scientific methods are how we learn about the natural world and reject the idea that science and faith speak to distinct and nonoverlapping domains.

And yet, teachers who are advocates of creationism also support teaching both sides. This is implicit in the fact that they spend at least one hour on creationism and some time on evolution, but it comes through in their comments as well. One creationist teacher from Indiana, for example, told us that “in teaching biology, I do not impart my belief on this subject to my students, I present each idea as a theory and let the students decide which one they want to believe in.” And a teacher from South Dakota who devotes eight hours to creationism and ten hours to evolution explained: “I teach evolution/creation as an inquiry process. I use classroom text as well as other sources backing evolution/creation. I have several useful videos backing both areas. My goal is to make students analyze and think to arrive at their own educated decisions.”

The Cautious Middle

Sixty percent of the teachers who completed the survey do not fall into either group of advocates. These teachers are in the cautious middle—a large and diverse group that utilizes a range of strategies to navigate the challenges posed by the sometimes competing expectations of state standards, administrators, school board members, students, and parents. About one in ten is a cautious or closet creationist: they do not qualify as “advocates” of creationism because they do not incorporate it into their lesson plans or spend as much as an hour on the topic. However, these closet creationists tell us that they validate creationism as credible science when prompted by student questions or comments.

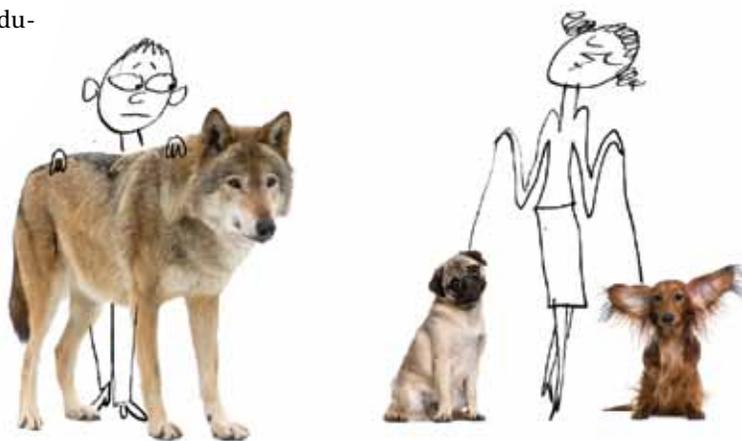
Most teachers in this middle group, 85 percent to be exact, accept evolution. What they have in common is that they cannot or will not teach what the major scientific organizations expect: that evolution is central to all biology, that evolution has occurred, and that hypotheses from evolutionary theory have been confirmed by many scientific studies. Instead, they employ a suite of techniques that reduce the likelihood of sparking some kind of controversy. In most cases, however, these are very nearly the same approaches taken by explicit creationist educators in support of the three pillars of modern creationism—approaches that undermine students’ confidence in science more generally and undercut their broader science education. Three controversy-avoidance techniques were mentioned often enough to merit some discussion: distinguishing between micro- and macroevolution, teaching to the test, and encouraging students to make up their own minds.

Micro- vs. Macroevolution: One common strategy to avoid stirring the deep feelings associated with evolution is to teach evolutionary biology as though it only applies to *within-species* change—often called microevolution. Teachers adopting this tactic deny their students exposure to a large body of evidence showing how natural selection leads to speciation and to the central concept of common ancestry of contemporary species.

For the anti-evolution movement, the micro-macro distinction serves to directly undermine the status of the major findings of evolutionary biology. “I distinguish microevolution as fact,” wrote an Indiana advocate of creationism, and “macroevolution as theory.”

However, most teachers in the middle group do not teach this way in order to narrow the scope of instruction; rather, they use the micro-macro distinction to make the material less controversial. So, for example, a teacher in California who offered sound pedagogical reasons for beginning with microevolution made it clear that she finds it less controversial to focus on this aspect of evolutionary theory:

I teach evolution through a cellular and molecular approach. I find students are less offended by it. The minute you start off with evolution showing primates or fossil evidence, students immediately shut down. On the other hand, when I



teach students the mechanisms of cells and that all cells basically are similar, then I can suggest evolution without so much opposition.

Pursuing this strategy may well limit exposure to angry parents and skeptical students. But this approach also lends credence to a creationist claim that there is no evidence for one species giving rise to others, and in doing so sacrifices a rich understanding of the diversity of life. One of modern creationism’s three pillars is that evolution—at least macroevolution—is not well-established science.* Excluding macroevolution, or teaching it as less scientifically established, plays directly into creationists’ hands.

Teaching to the Test: Statewide biology examinations are used in a growing number of states. In general, these examinations will promote more rigorous instruction in evolution so long as they are aligned with fairly rigorous standards.²⁶ And a teacher may enjoy some protection to teach the topic if the standards and tests require it.[†] But teachers in the cautious middle can also use these tests as a means to disassociate themselves from the very material they are expected to teach. In different ways, they defend their

*The well-known creationist Henry Morris put this well when he said that “the fact that macroevolution (as distinct from microevolution) has never been observed would seem to exclude it from the domain of true science.”²⁵

[†]For an interesting news feature about how a Georgia teacher used state standards to navigate community pressure and teach evolution, see <http://nyti.ms/GLmw6b>.

teaching of evolution as a necessary evil, something students just need to get through. One Michigan teacher tells her students that they need to understand evolution because the biology curriculum “is organized as if evolution is true.” A New York teacher said, “I have always started the evolution unit by telling the kids that I don’t care if they believe in evolution or not.... Just understand it enough to answer the Regents test questions.” Like many explicit creationist teachers, this teacher treats the acceptance of evolution as something students can choose to “believe in” and—intentionally or not—undercuts the principle that scientific methods are how we learn about the natural world.

More generally, when teachers disassociate themselves from the science by invoking the test, they undermine evolution in students’ minds. After all, a teacher would never tell students that he or she did not care if they actually believed that light simultaneously has the properties of waves and of discrete particles, or that the movement of massive plates is the cause of earthquakes.

It is not realistic to expect that students are equipped to assess and perhaps reject the thousands of scientific papers that form the empirical foundation of evolutionary theory.

Among established scientific principles, only evolution is so frequently approached as something that students need to know for the test, not because it is solid science. Indeed, an explicit advocate for creationism—a teacher from Texas—used nearly identical language when she told us that “I tell my students to learn the information for purposes of only passing the state test to graduate.”

Students are no doubt smart enough to pick up the message that underlies “just learn it for the test.” And we expect that in the future, some teachers will be tempted to use the same tactics of disassociation in order to avoid controversy concerning topics like climate change.

Students Should Make Up Their Own Minds: A third strategy used by teachers in the cautious middle is to argue that students should be exposed to explanations other than evolution—scientific or not. This, more than any other coping strategy, plays directly into the creationists’ hands. Bills and policies requiring or encouraging teachers to “teach the controversy” or to teach the “gaps” in evolution are an increasingly popular creationist tactic to undermine evolution. In many cases, these arguments are advanced as supporting “critical thinking” or “critical analysis.”²⁷ Students should make up their own minds, explained a Pennsylvania teacher, “based on their own beliefs and research. Not on what a textbook or on what a teacher says.”

This approach of letting students decide is used by advocates

of creationism as well because the “fairness” of teaching both sides is one of the three pillars of modern creationism. An Oklahoma teacher who was clear about her creationist beliefs and teaching policy was emphatic about this: “To be a true scien[tist], you have to present both evolution and creationism!” Another teacher, from Iowa, described her approach this way: “I let the students know up front that I have a creationist view point of how life was created. I use the word ‘model’ to explain evolution (‘evolution model’). I bring in the ‘intelligent design model’ to question the ‘evolution model.’ ”

Whether the teacher is trying to introduce creationism, hoping to avoid controversy, or simply manifesting great confidence in students’ ability to learn by exploration, the effect is the same. One teacher put it this way: “I encourage students to gather as much information as possible and make their own conclusions.” But it is simply not realistic to expect that, with only 10–15 class hours devoted to evolution, students are really equipped to assess and perhaps reject the thousands of peer-reviewed scientific papers that form the empirical foundation of evolutionary theory. This approach tells students that science is not a cumulative body of highly technical knowledge, but is instead something that has some element of personal preference, like whether Claude Monet created more beautiful paintings than Paul Cézanne.

We have argued in the past that the cautious 60 percent may play a far more important role in hindering scientific literacy in the United States than the 13 percent who are explicit creationist advocates.²⁸ The strategies of emphasizing microevolution, justifying the curriculum on the basis of statewide tests, or “teaching the controversy” are precisely the tactics employed by advocates of creationism. Creationists use these approaches because they undermine the legitimacy of findings that are well established by the combination of peer review and replication. They make it difficult for students to reconcile their religious beliefs with the established science. And they have the veneer of fairness. Afraid of doing anything that might upset student sensibilities, many of these cautious teachers may not fully explain the nature of scientific inquiry; as a result, they undermine the authority of established scientific experts and promote creationists’ political goals, even if unintentionally.

Sources of Ambivalence and Conflict Avoidance

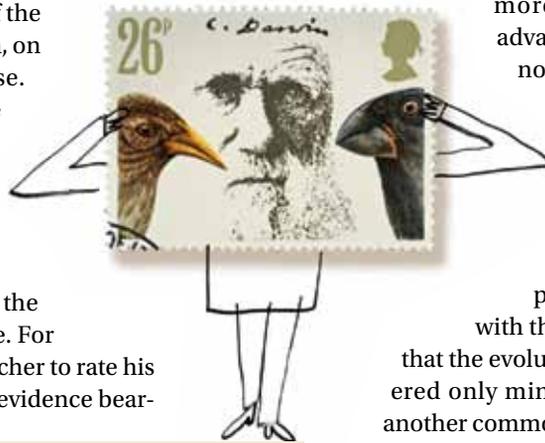
If most teachers in the cautious middle accept evolution personally, why do so many employ pedagogical approaches championed by the anti-evolution movement? Our research suggests that many teachers do not feel like they have the expertise they need to confidently teach evolutionary biology in a rigorous and unapologetic manner.²⁹ Those with inadequate content knowledge find that teaching evolution makes their jobs even more stressful; therefore, they gravitate toward strategies that reduce the likelihood of generating controversy. We can see evidence of this when we compare the responses of our three groups with a variety of questions pertaining to teachers’ pre-service education and personal assessments of how well they understand evolution.

Teachers' Content Knowledge

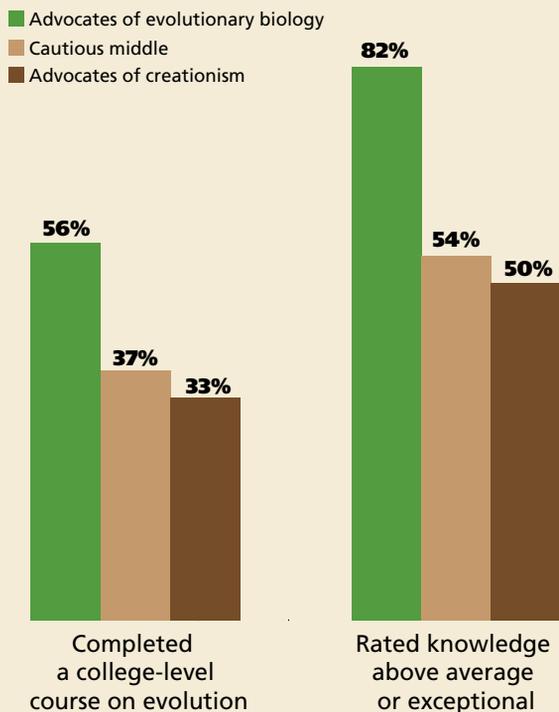
States' wide variety of certification requirements virtually ensures that not all science teachers are equally knowledgeable about evolutionary theory or science generally. A study of Indiana biology teachers, for example, found that many do not "possess a thorough knowledge of evolutionary theory and its place in the discipline of biology."³⁰

In our survey, we asked teachers about their pre-service college education. In the figure below, the set of bars on the left shows the percentage of teachers in each group who have completed a standalone course in evolution. This one indicator of teacher knowledge has a dramatic effect. More than 50 percent of the teachers who advocate evolution (green bar) have taken a college-level course in evolution. Only a third of the teachers who advocate creationism, on the other hand, took such a course. Teachers in the cautious middle look much like creationists, with slightly more than a third having completed a course in evolution (the small difference is not statistically significant).

Additional evidence is found in the set of bars on the right in the figure. For this, we asked each high school teacher to rate his or her "knowledge of the scientific evidence bear-



Percentage of teachers in each group who completed a college-level course on evolution and who rated their knowledge of evolution as above average or exceptional.



ing on the validity of evolutionary theory as": "Exceptional, on par with many college-level instructors"; "Very good compared to most high school biology teachers"; "Typical of most high school biology teachers"; or, they could admit, "I know less about this topic than many other high school biology teachers."

The question produces something of a "Lake Wobegon" effect, as 61 percent rated their knowledge as "above average" or "exceptional" and only 2 percent rated themselves below average. Nonetheless, the self-assessments of teachers form a striking pattern: teachers in the cautious middle are, once again, statistically indistinguishable from creationism advocates.

We also found that more science training in general makes a difference. For example, we found that the higher the number of college credit hours in biology, the more that teachers keep up with scientific advances by visiting science education websites, noting changes in new additions of their textbooks, and browsing scientific journals.

Not surprisingly, these related experiences are more common among teachers who rated their knowledge of evolution as exceptional. Teachers with more extensive content-based preparation are also much less likely to agree with the statement that "I have paced my class so that the evolution chapters in my textbook would be covered only minimally at the end of the academic term," another common avoidance strategy.

Why did we find that completing a college-level evolution course is so strongly related to teaching practices? Part of the answer is that many pre-service teachers who do not accept evolution will not select such a course as an elective. Overall, we have found that teachers who expressed creationist beliefs completed fewer courses in biology, were slightly less likely to major in a scientific field, and were considerably less likely to hold a graduate degree in a scientific discipline.³¹ However, for the 85 percent of teachers in the cautious middle who accept evolution, the completion of an evolution class provides content knowledge that translates directly into self-confidence. In many districts, teachers understand that each additional class hour devoted to evolution increases the likelihood of offending a student or getting an angry visit from a parent or local minister. Self-confidence is an important factor in how teachers approach these classes.³² While evolution can be a highly stressful topic, educational psychologists Joyce Griffith and Sarah Brem have shown it is less stressful for those teachers who are more confident and comfortable with the material.³³ So, taking evolution classes before beginning their teaching careers can directly increase teachers' self-confidence, which lowers their levels of stress heading into the course, and makes them much more likely to teach in ways that live up to the expectations of the National Research Council (and many other scientific societies).

One teacher from Illinois summed up these findings well: "After my undergraduate studies my perception of evolution was inaccurate. It wasn't til after I received a master of science that I felt like I had a good and accurate understanding of evolution and how natural selection happens." A master's degree in biology would probably be useful to biology teachers³⁴—but such a goal

cannot be accomplished right away. In the meantime, our research suggests that future teachers would benefit from a more rigorous pre-service education in biology and content-rich continuing education.

Preparing Teachers for the Coming Science Wars

In the coming decade, the United States will have to make important choices about energy policy (e.g., the safety of extracting oil and gas from shale deposits or of commissioning new nuclear reactors), the environment (e.g., the costs and benefits of policies to reduce carbon emissions), the wisdom of increasing our production of genetically modified foods, and much more. Because the disciplines of evolutionary biology, paleontology, climate science, and astrophysics each share similar methods with all

Teachers with creationist beliefs completed fewer courses in biology, were less likely to major in a scientific field, and were less likely to hold a graduate degree in a scientific discipline.

sciences, any undermining of children's trust in science—intentional or not—will have important consequences. If students come to think that science is simply a matter of one's opinion, and that those opinions come from our values and faith, then it will be impossible for science to provide trusted, unbiased information to citizens and policymakers.

What can be done to reverse this trend? In the case of evolution, we concur with the National Center for Science Education that “the most effective way for scientists to help to improve the understanding of evolution” is at the pre-service level.³⁵ Simply requiring a pre-service course in evolution is likely to provide cautious but well-intentioned teachers with the tools to address and minimize pressure from their communities with a greater degree of confidence.

Some have viewed our call for a required evolution course as nothing more than a call for indoctrination. But we believe the charge is misplaced. Indoctrination is requiring students to accept what they are taught whether or not there is evidence for it. But we are calling for pre-service teachers to learn what the evidence for evolution really is. This is the only way they can be expected and empowered to teach their students about that evidence when they are in the classroom. This is not a panacea, of course; research shows that evolution education has little impact on conservative Christians whose faith is a barrier to accepting evolution.³⁶ But our research suggests that completion of an evolution course can help teachers who already accept evolution do a better job of dealing with anti-science elements in their communities and of teaching evolution with both integrity and confidence.

More generally, the most effective long-term solution is for all future high school biology teachers to be expected to have considerably more training in biological and all other science. Likewise, pre-service teachers intending to teach at the primary and middle school levels would also benefit from additional opportunities to expand their content expertise.

Our hope is that educators will be supported by their administrators and community members so they can teach evolution, climate change, the antiquity of the universe, and any other socially controversial subject with the same commitment to scientific accuracy as when they teach other topics in science. We would never ask students to debate or make up their own minds about whether the atmosphere of Venus contains sulfuric acid, whether protons and electrons have opposite charges, or which gene on chromosome 11 is linked to sickle cell disease. Rather, to the extent possible at each grade level, we expect students to learn both scientific facts and what constitutes scientific evidence. As their knowledge and sophistication increase, so too will their understanding of the overwhelming evidence supporting evolution. Of course, teachers should emphasize that scientific findings (and even scientific theories) are always subject to revision, and are indeed sometimes revised—but not just in the case of evolution! However, this openness should never be a blank check that allows students to debate highly technical questions based on values and beliefs that come from outside the science classroom. To the extent that students are not convinced by the evidence before them, they should simply be encouraged to explore the available evidence further, in the reputable, peer-reviewed literature, and by enrolling in higher-level courses. If students' questions are met with opportunities for further learning, the next generation not only will have improved access to the STEM fields, but will become curious, thoughtful, and engaged citizens. □

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