

Overwhelming Scientific Confidence in Evolution and its Centrality in Science Education--And the Public Disconnect

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Abstract

The teaching and learning of biological evolution has been beset by a host of challenges ranging from pedagogical obstacles to social controversy. These include two distinctive sets of problems: one arising from the fact that many evolutionary concepts may seem counterintuitive to students, and the other stemming from objections rooted in religion. A misconception common to both of these categories is the notion that significant doubt exists within the scientific community as to whether evolution actually occurred, or that it is “a theory in crisis.” This article reviews the positions of the scientific and science education communities and how these compare with those of the general public. Despite the overwhelming acceptance of evolution among scientists, and despite evolution’s centrality to modern biology education, virtually all national polls indicate that a strikingly large proportion of North Americans reject evolution, indicating a great disconnect between the scientific community and the largely dissenting and apparently under-informed, or misinformed, public. Large-scale research efforts regarding current practices related to the instruction of evolution, and into more effective methods of teaching evolution, are needed; certainly in the United States, but urgently, even if surprisingly, in Canada.

Scientific Consensus on Evolution and its Centrality

Evolution, defined narrowly, is the scientific principle that the diversity of life on Earth has arisen via descent with modification from a common ancestry. In the broader sense, evolution can refer to cumulative change in the natural world over time (Scott, 2004). Under both of these definitions, evolution has been deemed by scientists and science educators alike as a central and unifying concept in the natural sciences, especially in biology.

To be sure, scientific claims are based on, and tested against, evidence drawn from the natural world, rather than dictated by an authoritarian leadership. Therefore, and nonetheless, the scientists who have gathered and analyzed the data that have shaped the scientific understanding of evolution are surely the most qualified to speak as to the nature and weight of the physical evidence. Likewise, professional practitioners and researchers in science education are naturally best situated to remark on the value and relative importance of a given concept when it comes to the teaching and learning of science. Herein, I offer a review of the positions of the scientific and science education communities, as they have been articulated by relevant scholars and their organizations, regarding evolution as defined above.

Expert Scientists on the Certainty of Evolution

It has become very nearly a cliché for authors, including this author, when writing on issues in life science education, to cite the famous proclamation of the revered geneticist Theodosius Dobzhansky (1973) that “nothing in biology makes sense except in the light of evolution” (p. 125). Perhaps this assertion is so frequently quoted because it “accurately reflects the central, unifying role of evolution in biology” (National Association of Biology Teachers, 2008, ¶ 1).

Dobzhansky (1973) is certainly not the only scientist to have made such a statement about evolution. The eminent palaeontologists Stephen Jay Gould (1983) and Robert Carroll (1997) both acknowledged the power of evolution to connect the broad and otherwise disjointed fields of the life sciences. Carroll called it “the greatest unifying principle of biology” (p. 1). The venerated biologist E. O. Wilson (1998) described evolutionary biology as being “linked by consilience to the rest of the natural sciences” (p.11), a statement in full accord with his long-time Harvard University colleague Ernst Mayr (1970), who explained that “the diversity of organisms, similarities and differences between kinds of organisms, patterns of distribution and behavior, adaptation and interaction” (p.1) were all “merely a bewildering chaos of facts” (p.1) before they were unified and given meaning through evolutionary theory.

Members of the general, non-scientist public are often confused by common conflation of the scientific and vernacular uses of the word *theory*. When used in casual, non-scientific parlance, the word is often understood to mean a guess or hunch (Scott, 2004). But in scientific terms, according to the National Academy of Sciences (NAS) (1998), a theory represents the pinnacle of the scientific enterprise. Referring to the NAS description of a theory, Eastwell (2009) elaborated: “A scientific theory is a set of statements that, when taken together, attempt to explain a broad class of related phenomena. Some theories have been modified or rejected, while others--the most useful ones--are standing the scientific test of time, which gives us increasing confidence in them” (p. 86). And there may not be a more useful or thoroughly substantiated body of knowledge in all of science than that of evolutionary theory.

To clarify, however, the occurrence of evolution is not itself a theory. That the genetic make-up of biological populations can change over generations and that the diversity of life on Earth today is drastically different than it was during previous periods of geologic history are demonstrably factual. *Evolutionary theory* encompasses these and other observable facts, as well as laws (e.g., the Hardy-Weinberg law), inferences, and a variety of competing and complementary theories regarding how (not whether) evolution occurs. And for at least a century and one half, a parade of scientists has endeavoured to communicate the difference between the fact of evolution itself and the explanatory body of evolutionary theory.

Charles Darwin (1859) listed sufficient evidence to assert the veracity of evolution in his *The Origin of Species*, and he affirmed the factuality of evolution in *The Descent of Man* while subtly and humbly admitting that the debate over his proposed mechanism was still somewhat tentative (Darwin, 1871). One hundred years after the publication of Darwin’s *Origin of Species*, the Nobel-Prize-winning geneticist H. J. Muller (1959) summed up a century’s worth of additional evidence and corroboration by saying:

So enormous, ramifying, and consistent has the evidence for evolution become that if anyone could now disprove it, I should have my conception of the orderliness of the universe so shaken as to lead me to doubt even my own existence. If you like, then, I will grant you that in an absolute sense evolution is not a fact, or rather, that it is no more a fact than that you are hearing or reading these words. (pp. 304-305)

As Mayr (1997) explained, the evidence for the occurrence of evolution is so overwhelming that today’s biologists “consider it a fact--as well-established as the fact that the Earth rotates around the sun and that the Earth is round and not flat” (p. 178).

In his final (i.e., non-posthumously) published book, Stephen Jay Gould (2002) devoted 1,343 pages to explaining *The Structure of Evolutionary Theory*. Gould's explanation is extensive, complex, and somewhat contentious, but he agreed with Mayr (1997) that the occurrence of evolution is indeed a fact. In an earlier essay, he described evolution as factual in that it has been "confirmed to such a degree that it would be perverse to withhold provisional assent" (Gould, 1983, p. 255). According to Gould, evolutionary theory involves explanations about the mechanisms of evolution, essentially how evolution occurred rather than whether it occurred.

Richard Lewontin (1981), another great Harvard evolutionary biologist, also sought to clarify what is fact and what is theory regarding evolution, writing:

Evolution is a fact, not theory [used in the colloquial sense of a guess or hunch] . . . what is at issue within biology are questions of details of the process and the relative importance of different mechanisms of evolution. It is a fact that the Earth with liquid water is more than 3.6 billion years old. It is a fact that cellular life has been around for at least half of that period and that organized multicellular life is at least 800 million years old. It is a fact that major life forms now on Earth were not at all represented in the past. There were no birds or mammals 250 million years ago. It is a fact that major life forms of the past are no longer living. There used to be dinosaurs and Pithecanthropus, and there are none now. It is a fact that all living forms come from previous living forms. Therefore, all present forms of life arose from ancestral forms that were different to them. Birds arose from non-birds and humans from non-humans. No person who pretends to any understanding of the natural world can deny these facts any more than she or he can deny that the Earth is round, rotates on its axis, and revolves around the sun. (p. 559)

Dobzhansky (1973) held that the occurrence of evolution has been "established beyond a reasonable doubt" (p.129), adding that "evolution as a process that has always gone on in the history of the Earth can be doubted only by those who are ignorant of the evidence or are resistant to evidence, owing to emotional blocks or to plain bigotry" (p.129).

In his widely-used, university-level textbook on evolutionary biology, Futuyma (1986) wrote:

The statement that organisms have descended with modifications from common ancestors--the historical reality of evolution--is not a theory. It is a fact, as fully as the fact of the earth's revolution about the sun. Like the heliocentric solar system, evolution began as a hypothesis, and achieved "facthood" as the evidence in its favor became so strong that no knowledgeable and unbiased person could deny its reality. (p. 15)

Famed scientists like Carl Sagan (1980), as well as Richard Dawkins and Jerry Coyne (2005), have also stated flatly that evolution is a fact. As Dawkins and Coyne elaborated, "evolution is a fact: as much a fact as plate tectonics or the heliocentric solar system" (p. 5).

These comments from prominent scientists are a mere smattering of such acknowledgments from individual experts regarding the factuality of evolution and its central and unifying role in science. It would be a monumental endeavour indeed to attempt to collect an exhaustive catalogue of qualified scientists who are in agreement with these assessments of the status of evolution. As further evidence of the essentially universal acceptance of evolution among the scientific community, consider the numerous statements in support of evolution offered by various groups of scientists.

Evolution is Overwhelmingly Accepted by the International Scientific Community

A panel of 72 Nobel laureates in the sciences signed a document agreeing that “the evolutionary history of organisms has been as extensively tested and as thoroughly corroborated as any biological concept” (Amici Curiae, 1986, Argument, Part 11, ¶ 10). The National Center for Science Education (NCSE) keeps a list, although it was admittedly compiled in jest, of scientists, all of whom hold doctorates in one of the natural sciences from accredited universities. These scientists have affirmed a statement that reads:

Evolution is a vital, well-supported, unifying principle of the biological sciences, and the scientific evidence is overwhelmingly in favor of the idea that all living things share a common ancestry. Although there are legitimate debates about the patterns and processes of evolution, there is no serious scientific doubt that evolution occurred or that natural selection is a major mechanism in its occurrence. (National Center for Science Education, 2008, ¶ 5; Scott et al., 2004, p. 26)

There are over 1000 signatories; but only scientists who are named Steve (or some cognate thereof, such as Stephanie, Esteban, Étienne, etc.) were permitted to sign. “Steve” was chosen in tribute to the late Stephen Jay Gould.

As for more officially organized groups of qualified scientists, many national academies of science and other professional scientific organizations have issued position statements regarding the overwhelming acceptance of evolution among the scientific community. For instance, as the Academy of Science of the Royal Society of Canada (RSC) (1985) attested:

The theory of evolution by natural selection was first clearly formulated in 1859, and for over a century it has been tested and improved by the research of many thousands of scientists: not only by biologists and geologists, but also by chemists and physicists. From deductions based on abundant data, the theory has been developed to explain the changes that have taken place in living things over much of the Earth’s history. In its modern form, it remains the only explanation for the diversity of life on this planet that is acceptable to the scientific community. (p. 21)

This position was reaffirmed by the RSC in 2006, adding that evolution is “the only credible scientific position” regarding the history of life on Earth and that “the teaching of evolution is a benchmark of legitimacy” for biology education (Demers, 2006, p. 84).

The American Institute of Biological Sciences (AIBS) is an umbrella organization comprising nearly 200 professional societies with a total individual membership of over 250,000. According to AIBS (1994), “as a community, biologists agree that evolution occurred and that the forces driving the evolutionary process are still active today. This consensus is based on more than a century of scientific data gathering and analysis” (p. 29).

The (United States) National Academy of Sciences (NAS) has addressed the certainty of the occurrence of evolution under its narrow, as well as its broad, definition. Excerpts from one statement issued by NAS (1984) read:

The processes by which new galaxies, stars, and our own planetary system are formed are sometimes referred to as the “evolution” of the universe, the stars, and the solar system. . . . Evidence that the evolution of the universe has taken place over at least several billion years is overwhelming. (pp. 11-12)

The same document concludes that biological evolution is also “supported by an overwhelming body of evidence” (NAS, p. 15) and that “evidence for relation by common descent has been provided by paleontology, comparative anatomy, biogeography, embryology, biochemistry, molecular genetics, and other biological disciplines (p. 15). The NAS reaffirmed this assessment in 2008, writing that evolution “is the only tested, comprehensive scientific explanation for the nature of the biological world today that is supported by overwhelming evidence and widely accepted by the scientific community” (NAS, 2008, p. 53).

The list of similar statements from scientific societies is long. Indeed, virtually every major scientific organization has issued a statement in support of evolution, and these statements have been neatly compiled as part of the National Center for Science Education’s *Voices for Evolution* project (Sager, 2008)¹. And they represent not only the positions of North American and European organizations, but those of the worldwide scientific community. In fact, no fewer than 67 national academies of science have attested that the evolution of galaxies, stars, planets, and of life on Earth over billions of years is supported by observations and experiments from all branches of the natural sciences and that the evolutionary sciences represent an extraordinarily interdisciplinary understanding of the history and workings of our planet and its inhabitants. As this cross-cultural body of the world’s most qualified experts attested, evolution is an “*evidence-based* fact . . . never contradicted” (Inter-Academy Panel, 2006, p. 1) by science. National academies of science from all inhabited continents and “representing countries from Albania to Zimbabwe” (National Center for Science Education, 2006, ¶ 1) were signatory to the Inter-Academy statement, including the African Academy of Science and the Academy of Sciences for the Developing World, which serve member scientists from countries having no formal academies of their own. Not only does this indicate the strength of the evidence for evolution, but also that evolution is not merely a construct of Western scientists and that informed acceptance of evolution as a factual phenomenon is not limited to any one culture.

Evolution’s Centrality in Science Education: Official Positions of the Science Education Community

The practically unanimous acceptance of the occurrence of evolution and recognition of its central and unifying position in science is not limited to professional scientists, but is in turn embraced by science educators who are trained in the sciences as well as in pedagogy. Consequently, most major science education organizations have also issued statements acknowledging the factuality of evolution and its power in unifying the sciences, especially biology (see Sager, 2008, pp. 127-185). Like many of the statements ratified by scientific societies, these statements generally endorse evolution as a foundational principle upon and around which to structure the teaching and learning of biology as well as science in general.

A section from one such statement issued by the National Science Teachers Association (NSTA), one of the world’s largest science education organizations, reads:

Evolution in the broadest sense can be defined as the idea that the universe has a history: that change through time has taken place. If we look today at the galaxies, stars, the planet Earth, and the life on planet Earth, we see that things today are different from what they were in the past: galaxies, stars, planets, and life forms have evolved.... There is abundant and consistent evidence from astronomy, physics, biochemistry, geochronology, geology, biology, anthropology, and other sciences that evolution has taken place. As such, evolution is a unifying concept for science. (NSTA, 2003, ¶ 7, 8)

This statement goes on to discuss evolution as an organizational principle for science teaching, citing the National Science Education Standards' recognition of evolution as a "conceptual scheme" that can "unify science disciplines and provide students with powerful ideas to help them understand the natural world" (National Research Council, 1996, p. 104).

The *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993) also offer evolution as an example of a unifying concept, and noting this, the NSTA concludes: "Scientific disciplines with a historical component, such as astronomy, geology, biology, and anthropology, cannot be taught with integrity if evolution is not emphasized" (NSTA, 2003, ¶ 8). Accordingly, the curriculum guidelines of most U.S. states (Gross et al., 2005; Lerner, 2000; Mead & Mates, 2009) prescribe the teaching of evolution in biology and other science courses. Moreover, evolution is prominently featured in most of the widely-used and highly-rated biology textbooks (Flammer, 2001; Morse, 2001).

Disconnect Between the Scientific Community and the General Public

Notwithstanding the overwhelming evidence supporting the occurrence of evolution; in defiance of the consonant assurance from the scientific community that evolution is factual; despite the insistence of all relevant authorities on science education that evolution is indispensable to effective teaching and meaningful understanding of biology; although evolution is widely represented in state, provincial, and national curriculum documents; and regardless of the coverage of evolution in science textbooks, a large portion of the North American public remains resistant, often resolutely so, to the notion of an evolutionary natural history, suggesting that they think scientists, teachers, and textbooks are simply wrong.

In the United States, polls have consistently shown that over one-third to about one-half of adults overtly reject evolution, and, over a span of 20 years, the percentage of adults in the U.S. who accept evolution declined from 45% to 40% (Miller, Scott, & Okamoto, 2006). Figures on the public acceptance of evolution in Canada are only marginally higher. An Angus Reid poll in 1993 found that 53% of Canadians surveyed disagreed with the statement "human beings as we know them today developed from earlier species of animals" (Sonderstrom, 2000, p. 16), and, although Brown and Delodder (2003) have questioned the methodology of the survey, a 2000 poll suggested that "Canadians are about evenly divided in their views about the origin of life" (Compas, 2000, p. 1). A more recent Angus Reid poll returned a slightly higher figure, 59%, for Canadians accepting evolution; however, only 37% of this population disagreed with the notion that dinosaurs and humans co-existed on Earth--a central claim among many evolution rejecters--which is a curious datum indeed (Angus Reid, 2007). And just as the all-but-universal acceptance of evolution among the scientific community is global in scope (Inter-Academy Panel, 2006), so, it seems, is the rejection of evolution by large proportions of the general populations of many countries worldwide (Asghar, Wiles, & Alters, 2007b; Branch, 2008; Chinsamy & Plagányi, 2007; Cornish-Bowden & Cárdenas, 2007; Miller et al., 2006; Numbers, 1992, 2004, 2006).

This widespread rejection of evolution among members of the general, non-scientist public has been lamented by a host of scientists and science educators. In their oft-cited article on teaching evolution, Alters and Nelson (2002) reported that most science educators and researchers consider the public understanding of evolution to be "woefully lacking" (p. 1891). In 1998, Randy Moore, who was then the editor of *The American Biology Teacher*, described the state of public understanding and rife rejection of evolution as "by far the biggest failure of science education from top to bottom" (Christensen, 1998, p. D3). And the situation has apparently not appreciably improved (Branch & Scott, 2008; Miller et al., 2006).

Battles over the teaching of evolution in the United States have been well publicized as religious activists have continuously attacked evolutionary science curricula for decades. The situation in Canada, however, appears to be of a different nature, and somewhat less visible, as the problem there may be more related to a general lack of evolution in the provincial curricula to begin with. It may be quite common for Canadian students to go through their entire public education without hearing about evolution (Savory, 2008; Wiles, 2006a), and the resulting lack of knowledge about evolution may leave its citizens vulnerable to anti-evolution evangelism. There are plenty of creationist groups currently operating in Canada, many with very active public outreach projects (Wiles, 2006a; Wiles, 2006b), and Canada's science curricula may become a target of choice for creationists owing to certain legal and logistical peculiarities. For one, the line separating church and state is less clearly drawn in Canada than it is in the U.S., and private religious schools--even those that teach creationism--are often provincially funded (Lampman, 2010). Furthermore, education systems in Canada are more centrally directed at the provincial level, unlike those of the States where education policy is largely determined at the local school district level. So Intelligent Design or other forms of creationist pseudoscience could conceivably find their way into provincially-prescribed curricula if even one Minister of Education or other high-ranking official is disposed to such policy. This is particularly troubling in light of the skepticism being levelled at the current Conservative government's allegedly anti-science agenda, including the appointment of a Science Minister who "won't confirm belief in evolution" (McIlroy, 2009).

It is difficult to be sure how much Canadian students know about evolution or what may influence their conceptions about evolutionary history. A recent attempt to determine whether the popularization of Intelligent Design Creationism had detrimentally impacted the teaching of evolution in the nation's schools was thwarted when the grant that would have funded the project was denied. Disturbingly, this proposal was rejected in part because the academic committee appointed by the Social Sciences and Humanities Research Council of Canada (SSHRC) determined that there was not "adequate justification for the assumption in the proposal that the theory of evolution, and not intelligent-design theory, was correct" (Bauslaugh, 2008, p. 57), which simultaneously discounts the enormous body of evidence for evolution, ignores the extensive body of knowledge encompassed by evolutionary theory, and inappropriately construes the religious doctrine of Intelligent Design Creationism as a scientific theory.

The disconnect between the positions of the science and science education communities and those of the general public may beg the question "what are we doing wrong?" Frustratingly, the answer to the question remains, to a large extent, "we do not know." We have learned much about what may influence student understanding and acceptance of evolution, what practices are more effective for teaching evolution, and what might influence teachers' decisions about what or whether to teach about evolution (Asghar, Wiles, & Alters, 2007a; Bishop & Anderson, 1990; Bybee, 2001; Cherif, Adams, & Loehr, 2001; Clough, 2006; Johnson & Peeples, 1987; Lawson & Worsnop, 1992; McComas, Clough, & Almazroa, 1998; Osif, 1997; Rudolph & Stewart, 1998; Rutledge & Warden, 2000; Ryan & Aikenhead, 1992; Scharmann & Harris, 1992; Summers, 1982; Trani, 2004). However, evaluations of what is *supposed* to be taught about evolution according to the official curricula of the United States have revealed high levels of variability. Although there has apparently been a general improvement among these standards in recent years, there have also been notable regressions (Lerner, 2000; Gross et al., 2005; Mead & Mates, 2009). Comprehensive analyses of Canadian curricula have yet to be completed, but, for both countries, we have yet to determine what is *actually* taught about evolution in North American science classrooms.

Berkman, Pacheco, and Plutzer (2008) produced the first "National Portrait" of how much time American biology teachers spend on evolution. A few of their less-surprising conclusions were that the more biology courses teachers take during their post-secondary training, the more time they devote to evolutionary concepts when teaching; that having taken at least one course in evolutionary biology substantially increases the amount of time teachers spend on evolution in their classrooms; and that the teaching of human evolution in particular tends to be scanted. Perhaps their most striking finding was that 1 in 8 teachers presents creationism as science, but particularly relevant here is the revelation that only 2% of the teachers surveyed reported that they excluded evolution from their instruction entirely (Berkman et al., 2008). If that is the case, then whatever is taught by the 98% of biology teachers who include evolution is apparently not sufficient to convince a large proportion of students that the science is sound. No such national survey has been conducted among Canadian science teachers, but until we know what students are really learning, or not learning, about evolution in our schools, we will have no way to determine, on the whole, what we as educators are doing wrong.

What we need are large-scale research efforts focused on evolution education at all academic levels in North America; including what students learn, what teachers teach, and how teachers are trained to teach about evolution. This information will be essential if we wish to effectively ameliorate the disconnect between the high degree of confidence among the scientific community and the ambivalence of the general public regarding the veracity and importance of evolutionary theory.

Note

¹*Voices for Evolution* also contains pro-evolution position statements issued by science education societies, civil liberties organizations, and the leadership bodies of several religious affiliations. The latter indicates that rejection of evolution is not a necessary component of conventional religious faith, as further attested by the *Clergy Letter Project*, with over 13,000 priests, preachers, pastors, ministers, rabbis, etc. signatory to a statement of their faith and the complimentary truth of scripture and evolutionary science (http://blue.butler.edu/~mzimmerm/Christian_Clergy/ChrClergyLtr.htm).

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