



## **Darwinism defined, the difference between fact and theory**

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**Stephen Jay Gould**

Charles Darwin, who was, perhaps, the most incisive thinker among the great minds of history, clearly divided his life's work into two claims of different character: establishing the fact of evolution, and proposing a theory (natural selection) for the mechanism of evolutionary change. He also expressed, and with equal clarity, his judgment about their different status: confidence in the facts of transmutation and genealogical connection among all organisms, and appropriate caution about his unproved theory of natural selection. He stated in the *Descent of Man*: "I had two distinct objects in view; firstly, to show that species had not been separately created, and secondly, that natural selection had been the chief agent of change . . . If I have erred in . . . having exaggerated its [natural selection's] power . . . I have at least, as I hope, done good service in aiding to overthrow the dogma of separate creations."

Darwin wrote those words more than a century ago. Evolutionary biologists have honored his fundamental distinction between fact and theory ever since. Facts are the world's data; theories are explanations proposed to interpret and coordinate facts. The fact of evolution is as well established as anything in science (as secure as the revolution of the earth about the sun), though absolute certainty has no place in our lexicon. Theories, or statements about the causes of documented evolutionary change, are now in a period of intense debate -- a good mark of science in its healthiest state. Facts don't disappear while

scientists debate theories. As I wrote in an early issue of this magazine (May 1981), "Einstein's theory of gravitation replaced Newton's, but apples did not suspend themselves in mid-air pending the outcome."

Since facts and theories are so different, it isn't surprising that these two components of science have had separate histories ever since Darwin. Between 1859 (the year of publication for the *Origin of Species*) and 1882 (the year of Darwin's death), nearly all thinking people came to accept the fact of evolution. Darwin lies beside Newton in Westminster Abbey for this great contribution. His theory of natural selection has experienced a much different, and checkered, history. It attracted some notable followers during his lifetime (Wallace in England, Weismann in Germany), but never enjoyed majority support. It became an orthodoxy among English-speaking evolutionists (but never, to this day, in France or Germany) during the 1930s, and received little cogent criticism until the 1970s. The past fifteen years have witnessed a revival of intense and, this time, highly fruitful debate as scientists discover and consider the implications of phenomena that expand the potential causes of evolution well beyond the unitary focus of strict Darwinism (the struggle for reproductive success among organisms within populations). Darwinian selection will not be overthrown; it will remain a central focus of more inclusive evolutionary theories. But new findings and interpretations at all levels, from molecular change in genes to patterns of overall diversity in geological time, have greatly expanded the scope of important causes -- from random, selectively neutral change at the genetic level, to punctuated equilibria and catastrophic mass extinction in geological time.

In this period of vigorous pluralism and intense debate among evolutionary biologists, I am greatly saddened to note that some distinguished commentators among non-scientists, in particular Irving Kristol in a *New York Times* Op Ed piece of Sept. 30, 1986 ("Room for Darwin and the Bible"), so egregiously misunderstand the character of our discipline and continue to confuse this central distinction between secure fact and healthy debate about theory.

I don't speak of the militant fundamentalists who label themselves with the oxymoron "scientific creationists," and try to sneak their Genesis literalism into high school classrooms under the guise of scientific dissent. I'm used to their rhetoric, their dishonest mis- and half-quotations, their constant repetition of "useful" arguments that even they must recognize as nonsense (disproved human footprints on dinosaur trackways in Texas, risible misinterpretation of thermodynamics to argue that life's complexity couldn't increase without a divine boost). Our struggle with these ideologues is political, not intellectual. I speak instead of our allies among people committed to reason and honorable argument.

Kristol, who is no fundamentalist, accuses evolutionary biologists of bringing their troubles with creationists upon themselves by too zealous an insistence upon the truths of Darwin's world. He writes: ". . . the debate has become a dogmatic crusade on both sides, and our educators, school administrators, and textbook publishers find themselves trapped in the middle." He places the primary blame upon a supposedly anti-religious stance in biological textbooks: "There is no doubt that most of our textbooks are still written as participants in the 'warfare' between science and religion that is our heritage from the 19th century. And there is also little doubt that it is this pseudoscientific dogmatism that has provoked the current religious reaction."

Kristol needs a history lesson if he thinks that current creationism is a product of scientific intransigence. Creationism, as a political movement against evolution, has been a continually powerful force since the days of the Scopes trial. Rather than using evolution to crusade against religion in their texts, scientists have been lucky to get anything at all about evolution into books for high school students ever since Scopes's trial in 1925. My own high school biology text, used in the liberal constituency of New York City in 1956, didn't even mention the word evolution. The laws that were used against Scopes and cowed textbook publishers into submission weren't overturned by the Supreme Court until 1968 (*Epperson v. Arkansas*).

But what about Kristol's major charge -- anti-religious prejudice and one-dimensional dogmatism about evolution in modern textbooks? Now we come to the heart of what makes me so sad about Kristol's charges and others in a similar vein. I don't deny that some texts have simplified, even distorted, in failing to cover the spectrum of modern debates; this, I fear, is a limitation of the genre itself (and the reason why I, though more of a writer than most scientists, have never chosen to compose a text). But what evidence can Kristol or anyone else provide to demonstrate that evolutionists have been worse than scientists from other fields in glossing over legitimate debate within their textbooks?

Consider the evidence. Two textbooks of evolution now dominate the field. One has as its senior author Theodosius Dobzhansky, the greatest evolutionist of our century, and a lifelong Russian Orthodox; nothing anti-religious could slip past his watchful eye. The second, by Douglas Futuyma, is a fine book by a kind and generous man who could never be dogmatic about anything except intolerance. (His book gives a fair hearing to my own heterodoxies, while dissenting from them.)

When we come to popular writing about evolution, I suppose that my own essays are as well read as any. I don't think that Kristol could include me among Darwinian dogmatists, for most of my essays focus upon my disagreements with the strict version of natural selection. I also doubt that Kristol would judge me anti-religious, since I have campaigned long and hard against the same silly dichotomy of science versus religion that he so rightly ridicules. I have written laudatory essays about several scientists (Burnet, Cuvier, Buckland, and Gosse, among others) branded as theological dogmatists during the nineteenth-century reaction; and, while I'm not a conventional believer, I don't consider myself irreligious.

Kristol's major error lies in his persistent confusion of fact with theory. He accuses us -- without giving a single concrete example, by the way -- of dogmatism about theory and sustains his charge by citing our confidence in the fact of transmutation. "It is reasonable to suppose that if evolution were taught more cautiously, as a conglomerate idea

consisting of conflicting hypotheses rather than as an unchallengeable certainty, it would be far less controversial."

Well, Mr. Kristol, evolution (as theory) is indeed "a conglomerate idea consisting of conflicting hypotheses," and I and my colleagues teach it as such. But evolution is also a fact of nature, and so do we teach it as well, just as our geological colleagues describe the structure of silicate minerals, and astronomers the elliptical orbits of planets.

Rather than castigate Mr. Kristol any further, I want to discuss the larger issue that underlies both this incident and the popular perception of evolution in general. If you will accept my premise that evolution is as well established as any scientific fact (I shall give the reasons in a moment), then why are we uniquely called upon to justify our chosen profession; and why are we alone subjected to such unwarranted infamy? To this central question of this essay, I suggest the following answer. We haven't received our due for two reasons: (1) a general misunderstanding of the different methods used by all historical sciences (including evolution), for our modes of inference don't match stereotypes of "the scientific method"; and (2) a continuing but unjustified fear about the implication both of evolution itself and of Darwin's theory for its mechanism. With these two issues resolved, we can understand both the richness of science (in its pluralistic methods of inquiry) and the absence of any conflict, through lack of common content, between proper science and true religion.

Our confidence in the fact of evolution rests upon copious data that fall, roughly, into three great classes. First, we have the direct evidence of small-scale changes in controlled laboratory experiments of the past hundred years (on bacteria, on almost every measurable property of the fruit fly *Drosophila*), or observed in nature (color changes in moth wings, development of metal tolerance in plants growing near industrial waste heaps), or produced during a few thousand years of human breeding and agriculture. Creationists can scarcely ignore this evidence, so they respond by arguing that God permits limited modification

within created types, but that you can never change a cat into a dog (who ever said that you could, or that nature did?).

Second, we have direct evidence for large-scale changes, based upon sequences in the fossil record. The nature of this evidence is often misunderstood by non-professionals who view evolution as a simple ladder of progress, and therefore expect a linear array of "missing links." But evolution is a copiously branching bush, not a ladder. Since our fossil record is so imperfect, we can't hope to find evidence for every tiny twiglet. (Sometimes, in rapidly evolving lineages of abundant organisms restricted to a small area and entombed in sediments with an excellent fossil record, we do discover an entire little bush -- but such examples are as rare as they are precious.) In the usual case, we may recover the remains of side branch number 5 from the bush's early history, then bough number 40 a bit later, then the full series of branches 156-161 in a well preserved sequence of younger rocks, and finally surviving twigs 250 and 287.

In other words, we usually find sequences of structural intermediates, not linear arrays of ancestors and descendants. Such sequences provide superb examples of temporally ordered evolutionary trends. Consider the evidence for human evolution in Africa. What more could you ask from a record of rare creatures living in terrestrial environments that provide poor opportunity for fossilization? We have a temporal sequence displaying clear trends in a suite of features, including threefold increase of brain size and corresponding decrease of jaws and teeth. (We are missing direct evidence for an earlier transition to upright posture, but wide-ranging and unstudied sediments of the right age have been found in East Africa, and we have an excellent chance to fill in this part of our story.) What alternative can we suggest to evolution? Would God -- for some inscrutable reason, or merely to test our faith -- create five species, one after the other (*Australopithecus afarensis*, *A. africanus*, *Homo habilis*, *H. erectus*, and *H. sapiens*), to mimic a continuous trend of evolutionary change?

Or, consider another example with evidence of structurally intermediate stages -- the transition from reptiles to mammals. The lower jaw of mammals contains but a single bone, the dentary. Reptiles build their lower jaws of several bones. In perhaps the most fascinating of those quirky changes in function that mark pathways of evolution, the two bones articulating the upper and lower jaws of reptiles migrate to the middle ear and become the malleus and incus (hammer and anvil) of mammals.

Creationists, ignorant of hard evidence in the fossil record, scoff at this tale. How could jaw bones become ear bones, they ask. What happened in between? An animal can't work with a jaw half disarticulated during the stressful time of transition.

The fossil record provides a direct answer. In an excellent series of temporally ordered structural intermediates, the reptilian dentary gets larger and larger, pushing back as the other bones of a reptile's lower jaw decrease in size. We've even found a transitional form with an elegant solution to the problem of remaking jaw bones into ear bones. This creature has a double articulation -- one between the two bones that become the mammalian hammer and anvil (the old reptilian joint), and a second between the squamosal and dentary bones (the modern mammalian condition). With this built-in redundancy, the emerging mammals could abandon one connection by moving two bones into the ear, while retaining the second linkage, which becomes the sole articulation of modern mammals.

Third, and most persuasive in its ubiquity, we have the signs of history preserved within every organism, every ecosystem, and every pattern of biogeographic distribution, by those pervasive quirks, oddities, and imperfections that record pathways of historical descent. These evidences are indirect, since we are viewing modern results, not the processes that caused them, but what else can we make of the pervasive pattern? Why does our body, from the bones of our back to the musculature of our belly, display the vestiges of an arrangement better

suited for quadrupedal life if we aren't the descendants of four-footed creatures? Why do the plants and animals of the Galapagos so closely resemble, but differ slightly from, the creatures of Ecuador, the nearest bit of land 600 miles to the east, especially when cool oceanic currents and volcanic substrate make the Galapagos such a different environment from Ecuador (thus removing the potential argument that God makes the best creatures for each place, and small differences only reflect a minimal disparity of environments)? The similarities can only mean that Ecuadorian creatures colonized the Galapagos and then diverged by a natural process of evolution.

This method of searching for oddities as vestiges of the past isn't peculiar to evolution, but a common procedure of all historical science. How, for example, do we know that words have histories, and haven't been decreed by some all-knowing committee in Mr. Orwell's bureau of New-speak? Doesn't the bucolic etymology of so many words testify to a different life style among our ancestors? In this article, I try to "broadcast" some ideas (a mode of sowing seed) in order to counter the most "egregious" of creationist sophistries (the animal ex grege, or outside the flock), for which, given the quid pro quo of business, this fine magazine pays me an "emolument" (the fee that millers once received to grind corn).

I don't want to sound like a shrill dogmatist shouting "rally round the flag boys," but biologists have reached a consensus, based on these kinds of data, about the fact of evolution. When honest critics like Irving Kristol misinterpret this agreement, they're either confusing our fruitful consonance about the fact of evolution with our vibrant dissonance about mechanisms of change, or they've misinterpreted part of our admittedly arcane technical literature.

One such misinterpretation has gained sufficient notoriety in the last year that we crave resolution both for its own sake and as an illustration of the frustrating confusion that can arise when scientists aren't clear and when commentators, as a result of hidden agendas, don't listen. Tom Bethell argued in Harper's (February 1985) that a group of young



taxonomists called pattern cladists have begun to doubt the existence of evolution itself.

This would be truly astounding news, since cladistics is a powerful method dedicated to reforming classification by using only the branching order of lineages on evolutionary trees ("propinquity of descent" in Darwin's lovely phrase), rather than vague notions of overall similarity in form or function. (For example, in the cladistic system, a lungfish is more closely related to a horse than to a salmon because the common ancestor of lungfish and horse is more recent in time than the link point of the lungfish-horse lineage with the branch leading to modern bony fishes (including salmon).

Cladists use only the order of branching to construct their schemes of relationships; it bothers them not a whit that lungfish and salmon look and work so much alike. Cladism, in other words, is the purest of all genealogical systems for classification, since it works only with closeness of common ancestry in time. How preciously ironic then, that this most rigidly evolutionary of all taxonomic systems should become the subject of such extraordinary misunderstanding -- as devised by Bethell, and perpetuated by Kristol when he writes: ". . . many younger biologists (the so-called 'cladists') are persuaded that the differences among species -- including those that seem to be closely related -- are such as to make the very concept of evolution questionable."

This error arose for the following reason. A small splinter group of cladists (not all of them, as Kristol claims) -- "transformed" or "pattern" cladists by their own designation -- have adopted what is to me an ill-conceived definition of scientific procedure. They've decided, by misreading Karl Popper's philosophy, that patterns of branching can be established unambiguously as a fact of nature, but that processes causing events of branching, since they can't be observed directly, can't be known with certainty. Therefore, they say, we must talk only of pattern and rigidly exclude all discussion of process (hence "pattern cladistics").

This is where Bethell got everything arse-backwards and began the whole confusion. A philosophical choice to abjure all talk about process isn't the same thing as declaring that no reason for patterns of branching exists. Pattern cladists don't doubt that evolution is the cause behind branching; rather, they've decided that our science shouldn't be discussing causes at all.

Now I happen to think that this philosophy is misguided; in unguarded moments I would even deem it absurd. Science, after all, is fundamentally about process; learning why and how things happen is the soul of our discipline. You can't abandon the search for cause in favor of a dry documentation of pattern. You must take risks of uncertainty in order to probe the deeper questions, rather than stopping with sterile security. You see, now I've blown our cover. We scientists do have our passionate debates -- and I've just poured forth an example. But as I wrote earlier, this is a debate about the proper approach to causes, not an argument about whether causes exist, or even whether the cause of branching is evolution or something else. No cladist denies that branching patterns arise by evolution.

This incident also raises the troubling issue of how myths become beliefs through adulterated repetition without proper documentation. Bethell began by misunderstanding pattern cladistics, but at least he reports the movement as a small splinter, and tries to reproduce their arguments. Then Kristol picks up the ball and recasts it as a single sentence of supposed fact -- and all cladists have now become doubters of evolution by proclamation. Thus a movement, by fiat, is turned into its opposite -- as the purest of all methods for establishing genealogical connections becomes a weapon for denying the mechanism that all biologists accept as the cause of branching on life's tree: evolution itself. Our genealogy hasn't been threatened, but my geniality has almost succumbed.

When I ask myself why the evidence for evolution, so clear to all historical scientists, fails to impress intelligent nonscientists, I must believe that more than simple misinformation lies at the root of our difficulty with a man like Irving Kristol. I believe that the main problem

centers upon a restrictive stereotype of scientific method accepted by most non-practitioners as the essential definition of all scientific work.

We learn in high school about the scientific method -- a cut- and-dried procedure of simplification to essential components, experiment in the controlled situation of a laboratory, prediction and replication. But the sciences of history -- not just evolution but a suite of fundamental disciplines ranging from geology, to cosmology, to linguistics -- can't operate by this stereotype. We are charged with explaining events of extraordinary complexity that occur but once in all their details. We try to understand the past, but don't pretend to predict the future. We can't see past processes directly, but learn to infer their operation from preserved results.

Science is a pluralistic enterprise with a rich panoply of methods appropriate for different kinds of problems. Past events of long duration don't lie outside the realm of science because we cannot make them happen in a month within our laboratory. Direct vision isn't the only, or even the usual, method of inference in science. We don't see electrons, or quarks, or chemical bonds, any more than we see small dinosaurs evolve into birds, or India crash into Asia to raise the Himalayas.

William Whewell, the great English philosopher of science during the early nineteenth century, argued that historical science can reach conclusions, as well confirmed as any derived from experiment and replication in laboratories, by a method he called "consilience" (literally "jumping together") of inductions. Since we can't see the past directly or manipulate its events, we must use the different tactic of meeting history's richness head on. We must gather its wondrously varied results and search for a coordinating cause that can make sense of disparate data otherwise isolated and uncoordinated. We must see if a set of results so diverse that no one had ever considered their potential coordination might jump together as the varied products of a single process. Thus plate tectonics can explain magnetic stripes on the sea floor, the rise and later erosion of the Appalachians, the earthquakes of Lisbon and San Francisco, the eruption of Mount St. Helens, the

presence of large flightless ground birds only on continents once united as Gondwanaland, and the discovery of fossil coal in Antarctica.

Darwin, who understood the different rigor of historical sciences so well, complained bitterly about those critics who denied scientific status to evolution because they couldn't see it directly or reproduce its historical results in a laboratory. He wrote to Hooker in 1861: "Change of species cannot be directly proved . . . The doctrine must sink or swim according as it groups and explains phenomena. It is really curious how few judge it in this way, which is clearly the right way." And later, in 1868: "This hypothesis may be tested . . . by trying whether it explains several large and independent classes of facts; such as the geological succession of organic beings, their distribution in past and present times, and their mutual affinities and homologies."

If a misunderstanding of the different methods of historical inquiry has impeded the recognition of evolution as a product of science at its best, then a residual fear for our own estate has continued to foster resentment of the fact that our physical bodies have ancient roots in ape-like primates, waddling reptiles, jawless fishes, worm-like invertebrates, and other creatures deemed even lower or more ignoble. Our ancient hopes for human transcendence have yet to make their peace with Darwin's world.

But what challenge can the facts of nature pose to our own decisions about the moral value of our lives? We are what we are, but we interpret the meaning of our heritage as we choose. Science can no more answer the questions of how we ought to live than religion can decree the age of the earth. Honorable and discerning scientists (most of us, I trust) have always understood that the limits to what science can answer also describe the power of its methods in their proper domain. Darwin himself exclaimed that science couldn't touch the problem of evil and similar moral conundrums: "A dog might as well speculate on the mind of Newton. Let each man hope and believe what he can."

There is no warfare between science and religion, never was except as a historical vestige of shifting taxonomic boundaries among disciplines. Theologians haven't been troubled by the fact of evolution, unless they try to extend their own domain beyond its proper border (hubris and territorial expansionism aren't the sins of scientists alone, despite Mr. Kristol's fears). The Reverend Henry Ward Beecher, our greatest orator during Darwin's century, evoked the most quintessential of American metaphors in dismissing the entire subject of conflict between science and religion with a single epithet: "Design by wholesale is grander than design by retail" --or, general laws rather than creation of each item by fiat will satisfy our notion of divinity.

Similarly, most scientists show no hostility to religion. Why should we, since our subject doesn't intersect the concerns of theology? I strongly dispute Kristol's claim that "the current teaching of evolution in our public schools does indeed have an ideological bias against religious belief." Unless at least half my colleagues are inconsistent dunces, there can be -- on the most raw and direct empirical grounds -- no conflict between science and religion. I know hundreds of scientists who share a conviction about the fact of evolution, and teach it in much the same way. Among these people I note an entire spectrum of religious attitudes -- from devout daily prayer and worship to resolute atheism. Either there's no correlation between religious belief and confidence in evolution -- or else half these people are fools.

The common goal of science and religion is our shared struggle for wisdom in all its various guises. I know no better illustration of this great unity than a final story about Charles Darwin. This scourge of fundamentalism had a conventional church burial -- in Westminster Abbey no less. J. Frederick Bridge, Abbey organist and Oxford don, composed a funeral anthem especially for the occasion. It may not rank high in the history of music, but it is, as my chorus director opined, a "sweet piece." (I've made what may be the only extant recording of this work, marred only by the voice of yours truly within the bass section.) Bridge selected for his text the finest biblical description of the common

aim that will forever motivate both the directors of his building and the inhabitants of the temple of science -- wisdom. "Her ways are ways of pleasantness and all her paths are peace" (Proverbs 3:17).

I am only sorry that Dr. Bridge didn't set the very next metaphor about wisdom (Proverbs 3:18), for it describes, with the proper topology of evolution itself, the greatest dream of those who followed the God of Abraham, Isaac, and Jacob: "She is a tree of life to them that lay hold upon her."

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