
STEPHEN JAY GOULD

Evolution as Fact and Theory*

*Stephen Jay Gould received his doctorate from Columbia University in 1967 and is currently Professor of Zoology and curator of paleontology at Harvard University. The author of many scientific works, Gould has also written extensively for a wider audience. Books such as *The Panda's Thumb* (1980), *The Mismeasure of Man* (1981), and *Eight Little Piggies: Reflections in Natural History* (1993) are much admired for their style and their accessibility to the general reader.*

*In the following selection from *Hen's Teeth and Horses Toes* (1983), Gould discusses Darwin's theory of evolution in the context of the Creationist attack. Central to this attack, he points out, is a misunderstanding of the nature of scientific theory and of the principle of falsifiability. These issues are engaged elsewhere in this Part; see especially Wynn, Hawking, and Popper.*

Kirtley Mather, who died last year at age ninety, was a pillar of both science and Christian religion in America and one of my dearest friends. The difference of a half-century in our ages evaporated before our common interests. The most curious thing we shared was a battle we each fought at the same age. For Kirtley had gone to Tennessee with Clarence Darrow to testify for evolution at the Scopes trial of 1925. When I think that we are enmeshed again in the same struggle for one of the best documented, most compelling and exciting concepts in all of science, I don't know whether to laugh or cry.

According to idealized principles of scientific discourse, the arousal of dormant issues should reflect fresh data that give renewed life to abandoned notions. Those outside the current debate may therefore be excused for suspecting that creationists have come up with something new, or that evolutionists have generated some serious internal trouble. But nothing has changed; the creationists have presented not a single new fact or argument. Darrow and Bryan were at least more entertaining than we lesser antagonists today. The rise of creationism is politics, pure and simple; it represents one issue (and by no means the major concern) of the resurgent evangelical right. Arguments that seemed kooky just a decade ago have reentered the mainstream.

The basic attack of modern creationists falls apart on two general counts before we even reach the supposed factual details of their assault against evolution. First, they play upon a vernacular misunderstanding of the word "theory" to convey the false impression that we evolutionists are covering up the rotten core of our edifice. Second, they misuse a popular philosophy of science to argue that they are behaving scientifically in attacking evolution. Yet the same philosophy demonstrates that their own belief is not science, and that "scientific creationism" is a meaningless and self-contradictory phrase, an example of what Orwell called "newspeak."

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In the American vernacular, "theory" often means "imperfect fact"—part of a hierarchy of confidence running downhill from fact to theory to hypothesis to guess. Thus, creationists can (and do) argue: evolution is "only" a theory, and intense debate now rages about many aspects of the theory. If evolution is less than a fact, and scientists can't even make up their minds about the theory, then what confidence can we have in it? Indeed, President Reagan echoed this argument before an evangelical group in Dallas when he said (in what I devoutly hope was campaign rhetoric): "Well, it is a theory. It is a scientific theory only, and it has in recent years been challenged in the world of science—that is, not believed in the scientific community to be as infallible as it once was."

Well, evolution is a theory. It is also a fact. And facts and theories are different things, not rungs in a hierarchy of increasing certainty. Facts are the world's data. Theories are structures of ideas that explain and interpret facts. Facts do not go away while scientists debate rival theories for explaining them. Einstein's theory of gravitation replaced Newton's, but apples did not suspend themselves in mid-air pending the outcome. And human beings evolved from apelike ancestors whether they did so by Darwin's proposed mechanism or by some other, yet to be discovered.

Moreover, "fact" does not mean "absolute certainty." The final proofs of logic and mathematics flow deductively from stated premises and achieve certainty only because they are *not* about the empirical world. Evolutionists make no claim for perpetual truth, though creationists often do (and then attack us for a style of argument that they themselves favor). In science, "fact" can only mean "confirmed to such a degree that it would be perverse to withhold provisional assent." I suppose that apples might start to rise tomorrow, but the possibility does not merit equal time in physics classrooms.

Evolutionists have been clear about this distinction between fact and theory from the very beginning, if only because we have always acknowledged how far we are from completely understanding the mechanisms (theory) by which evolution (fact) occurred. Darwin continually emphasized the difference between his two great and separate accomplishments: establishing the fact of evolution, and proposing a theory—natural selection—to explain the mechanism of evolution. He wrote 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 . . . Hence 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."

Thus Darwin acknowledged the provisional nature of natural selection while affirming the fact of evolution. The fruitful theoretical debate that Darwin initiated has never ceased. From the 1940s through the 1960s, Darwin's own theory of natural selection did achieve a temporary hegemony that it never enjoyed in his lifetime. But renewed debate characterizes our decade, and, while no biologist questions the importance of natural selection, many now doubt its ubiquity. In particular, many evolutionists argue that substantial amounts of genetic change may not be subject to natural selection and may spread through populations at random. Others are challenging Darwin's

linking of natural selection with gradual, imperceptible change through all intermediary degrees; they are arguing that most evolutionary events may occur far more rapidly than Darwin envisioned.

Scientists regard debates on fundamental issues of theory as a sign of intellectual health and a source of excitement. Science is—and how else can I say it?—most fun when it plays with interesting ideas, examines their implications, and recognizes that old information may be explained in surprisingly new ways. Evolutionary theory is now enjoying this uncommon vigor. Yet amidst all this turmoil no biologist has been led to doubt the fact that evolution occurred; we are debating *how* it happened. We are all trying to explain the same thing: the tree of evolutionary descent linking all organisms by ties of genealogy. Creationists pervert and caricature this debate by conveniently neglecting the common conviction that underlies it, and by falsely suggesting that we now doubt the very phenomenon we are struggling to understand.

Secondly, creationists claim that "the dogma of separate creations," as Darwin characterized it a century ago, is a scientific theory meriting equal time with evolution in high school biology curricula. But a popular viewpoint among philosophers of science belies this creationist argument. Philosopher Karl Popper has argued for decades that the primary criterion of science is the falsifiability of its theories. We can never prove absolutely, but we can falsify. A set of ideas that cannot, in principle, be falsified is not science.

The entire creationist program includes little more than a rhetorical attempt to falsify evolution by presenting supposed contradictions among its supporters. Their brand of creationism, they claim, is "scientific" because it follows the Popperian model in trying to demolish evolution. Yet Popper's argument must apply in both directions. One does not become a scientist by the simple act of trying to falsify a rival and truly scientific system; one has to present an alternative system that also meets Popper's criterion—it too must be falsifiable in principle.

"Scientific creationism" is a self-contradictory, nonsense phrase precisely because it cannot be falsified. I can envision observations and experiments that would disprove any evolutionary theory I know, but I cannot imagine what potential data could lead creationists to abandon their beliefs. Unbeatable systems are dogma, not science. Lest I seem harsh or rhetorical, I quote creationism's leading intellectual, Duane Gish, Ph.D., from his book, *Evolution? The Fossils Say No!* "By creation we mean the bringing into being by a supernatural Creator of the basic kinds of plants and animals by the process of sudden, or fiat, creation. We do not know how the Creator created, what processes He used, for He used processes which are not now operating anywhere in the natural universe [Gish's italics]. This is why we refer to creation as special creation. We cannot discover by scientific investigations anything about the creative processes used by the Creator." Pray tell, Dr. Gish, in the light of your last sentence, what then is "scientific" creationism?

Our confidence that evolution occurred centers upon three general arguments. First, we have abundant, direct, observational evidence of evolution in action, from both field and laboratory. This evidence ranges from countless experiments on change in nearly everything about fruit flies subjected to artificial selection in the laboratory to the famous populations of British moths that became black when industrial soot

darkened the trees upon which the moths rest. (Moths gain protection from sharp-sighted bird predators by blending into the background.) Creationists do not deny these observations; how could they? Creationists have tightened their act. They now argue that God only created "basic kinds," and allowed for limited evolutionary meandering within them. Thus toy poodles and Great Danes come from the dog kind and moths can change color, but nature cannot convert a dog to a cat or a monkey to a man.

The second and third arguments for evolution—the case for major changes—do not involve direct observation of evolution in action. They rest upon inference, but are no less secure for that reason. Major evolutionary change requires too much time for direct observation on the scale of recorded human history. All historical sciences rest upon inference, and evolution is no different from geology, cosmology, or human history in this respect. In principle, we cannot observe processes that operated in the past. We must infer them from results that still surround us: living and fossil organisms for evolution, documents and artifacts for human history, strata and topography for geology.

The second argument—that the imperfection of nature reveals evolution—strikes many people as ironic, for they feel that evolution should be most elegantly displayed in the nearly perfect adaptation expressed by some organisms—the camber of a gull's wing, or butterflies that cannot be seen in ground litter because they mimic leaves so precisely. But perfection could be imposed by a wise creator or evolved by natural selection. Perfection covers the tracks of past history. And past history—the evidence of descent—is the mark of evolution.

Evolution lies exposed in the *imperfections* that record a history of descent. Why should a rat run, a bat fly, a porpoise swim, and I type this essay with structures built of the same bones unless we all inherited them from a common ancestor? An engineer, starting from scratch, could design better limbs in each case. Why should all the large native mammals of Australia be marsupials, unless they descended from a common ancestor isolated on this island continent? Marsupials are not "better," or ideally suited for Australia; many have been wiped out by placental mammals imported by man from other continents. This principle of imperfection extends to all historical sciences. When we recognize the etymology of September, October, November, and December (seventh, eighth, ninth, and tenth), we know that the year once started in March, or that two additional months must have been added to an original calendar of ten months.

The third argument is more direct: transitions are often found in the fossil record. Preserved transitions are not common—and should not be, according to our understanding of evolution—but they are not entirely wanting, as creationists often claim. The lower jaw of reptiles contains several bones, that of mammals only one. The non-mammalian jawbones are reduced, step by step, in mammalian ancestors until they become tiny nubbins located at the back of the jaw. The "hammer" and "anvil" bones of the mammalian ear are descendants of these nubbins. How could such a transition be accomplished? the creationists ask. Surely a bone is either entirely in the jaw or in the ear. Yet paleontologists have discovered two transitional lineages of therapsids (the so-called mammal-like reptiles) with a double jaw joint—one composed of the old quadrate and articular bones (soon to become the hammer and anvil), the other of the squamos-

al and dentary bones (as in modern mammals). For that matter, what better transitional form could we expect to find than the oldest human, *Australopithecus afarensis*, with its apelike palate, its human upright stance, and a cranial capacity larger than any ape's of the same body size but a full 1,000 cubic centimeters below ours? If God made each of the half-dozen human species discovered in ancient rocks, why did he create in an unbroken temporal sequence of progressively more modern features—increasing cranial capacity, reduced face and teeth, larger body size? Did he create to mimic evolution and test our faith thereby?

Faced with these facts of evolution and the philosophical bankruptcy of their own position, creationists rely upon distortion and innuendo to buttress their rhetorical claim. If I sound sharp or bitter, indeed I am—for I have become a major target of these practices.

I count myself among the evolutionists who argue for a jerky, or episodic, rather than a smoothly gradual, pace of change. In 1972 my colleague Niles Eldredge and I developed the theory of punctuated equilibrium. We argued that two outstanding facts of the fossil record—geologically "sudden" origin of new species and failure to change thereafter (stasis)—reflect the predictions of evolutionary theory, not the imperfections of the fossil record. In most theories, small isolated populations are the source of new species, and the process of speciation takes thousands or tens of thousands of years. This amount of time, so long when measured against our lives, is a geological microsecond. It represents much less than 1 per cent of the average lifespan for a fossil invertebrate species—more than ten million years. Large, widespread, and well-established species, on the other hand, are not expected to change very much. We believe that the inertia of large populations explains the stasis of most fossil species over millions of years.

We proposed the theory of punctuated equilibrium largely to provide a different explanation for pervasive trends in the fossil record. Trends, we argued, cannot be attributed to gradual transformation within lineages, but must arise from the differential success of certain kinds of species. A trend, we argued, is more like climbing a flight of stairs (punctuations and stasis) than rolling up an inclined plane.

Since we proposed punctuated equilibria to explain trends, it is infuriating to be quoted again and again by creationists—whether through design or stupidity, I do not know—as admitting that the fossil record includes no transitional forms. Transitional forms are generally lacking at the species level, but they are abundant between larger groups. Yet a pamphlet entitled "Harvard Scientists Agree Evolution Is a Hoax" states: "The facts of punctuated equilibrium which Gould and Eldredge . . . are forcing Darwinists to swallow fit the picture that Bryan insisted on, and which God has revealed to us in the Bible."

Continuing the distortion, several creationists have equated the theory of punctuated equilibrium with a caricature of the beliefs of Richard Goldschmidt, a great early geneticist. Goldschmidt argued, in a famous book published in 1940, that new groups can arise all at once through major mutations. He referred to these suddenly transformed creatures as "hopeful monsters." (I am attracted to some aspects of the

non-caricatured version, but Goldschmidt's theory still has nothing to do with punctuated equilibrium. Creationist Luther Sunderland talks of the "punctuated equilibrium hopeful monster theory" and tells his hopeful readers that "it amounts to tacit admission that anti-evolutionists are correct in asserting there is no fossil evidence supporting the theory that all life is connected to a common ancestor." Duane Gish writes, "According to Goldschmidt, and now apparently according to Gould, a reptile laid an egg from which the first bird, feathers and all, was produced." Any evolutionist who believed such nonsense would rightly be laughed off the intellectual stage; yet the only theory that could ever envision such a scenario for the origin of birds is creationism—with God acting in the egg.

I am both angry at and amused by the creationists; but mostly I am deeply sad. Sad for many reasons. Sad because so many people who respond to creationist appeals are troubled for the right reason, but venting their anger at the wrong target. It is true that scientists have often been dogmatic and elitist. It is true that we have often allowed the white-coated, advertising image to represent us—"Scientists say that Brand X cures bunions ten times faster than . . ." We have not fought it adequately because we derive benefits from appearing as a new priesthood. It is also true that faceless and bureaucratic state power intrudes more and more into our lives and removes choices that should belong to individuals and communities. I can understand that school curricula, imposed from above and without local input, might be seen as one more insult on all these grounds. But the culprit is not, and cannot be, evolution or any other fact of the natural world. Identify and fight your legitimate enemies by all means, but we are not among them.

I am sad because the practical result of this brouhaha will not be expanded coverage to include creationism (that would also make me sad), but the reduction or excision of evolution from high school curricula. Evolution is one of the half dozen "great ideas" developed by science. It speaks to the profound issues of genealogy that fascinate all of us—the "roots" phenomenon writ large. Where did we come from? Where did life arise? How did it develop? How are organisms related? It forces us to think, ponder, and wonder. Shall we deprive millions of this knowledge and once again teach biology as a set of dull and unconnected facts, without the thread that weaves diverse material into a supple unity?

But most of all I am saddened by a trend I am just beginning to discern among my colleagues. I sense that some now wish to mute the healthy debate about theory that has brought new life to evolutionary biology. It provides grist for creationist mills, they say, even if only by distortion. Perhaps we should lie low and rally round the flag of strict Darwinism, at least for the moment—a kind of old-time religion on our part.

But we should borrow another metaphor and recognize that we too have to tread a straight and narrow path, surrounded by roads to perdition. For if we ever begin to suppress our search to understand nature, to quench our own intellectual excitement in a misguided effort to present a united front where it does not and should not exist, then we are truly lost.

QUESTIONS FOR DISCUSSION

1. Why, according to Gould, is "scientific creationism" a "meaningless and self-contradictory phrase"?
2. Gould says that he can "envision observations and experiments that would disprove any evolutionary theory" he knows. What might some such observations/experiments be?
3. Do you agree with Gould that arguments based on inference can be—and in the case of evolution are—just as "secure" as those based on "direct observation"?
4. Gould says that "all historical sciences rest upon inference." Should we infer that inference is not involved in non-historical sciences?
5. Why is Gould "most . . . saddened" by what he perceives as a trend among his scientific colleagues to present a "united front" against the creationists? In what sense would "we" be "truly lost"?

MAX WERTHEIMER

Einstein: The Thinking That Led to the Theory of Relativity*

The philosopher and psychologist Max Wertheimer was born in Prague and educated there and in Germany, receiving his Ph.D. from the University of Würzburg in 1904. After teaching for twelve years at the University of Berlin, he emigrated to the United States in 1934. From that year until his death in 1943, he was Professor of Psychology and Philosophy at the New School for Social Research in New York.

As co-founder of Gestalt theory, Wertheimer had a profound influence on twentieth-century thought. Indeed, his insights into the processes of perception changed our understanding of thinking itself. In a series of brilliantly conceived and scientifically exacting experiments, he was able to show, for example, that the parts of a given process (including the process of perception) cannot be understood independently of their place in the whole. For Wertheimer, this notion had special relevance for scientific investigation, with its tendency to analyze the parts of a system in isolation.

*In the following essay, taken from *Productive Thinking* (1945), Wertheimer dramatizes the thought processes by which Einstein struggled toward the theory that recast modern physics and reshaped our understanding of the universe. This piece goes well with Popper (this Part) and with Kneller and Bauer (Part I).*

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