Planck's Principle

Do younger scientists accept new scientific ideas with greater alacrity than older scientists?

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Summary. Two views about the Darwinian revolution are tested: that nearly all scientists in Great Britain had been converted to a belief in the evolution of species within 10 years after the publication of the *Origin of Species*, and that younger scientists were converted much more rapidly than older scientists. Both views are shown to be less than accurate.

One of the most controversial questions concerning the nature of scientific change is the extent to which it is affected by "internal" versus "external" considerations. At one extreme are those who maintain that new ideas triumph in science primarily because the empirical evidence supports them more strongly than any of their competitors. Particular scientists may be influenced to some extent by peculiarities of their psychological makeup and social milieu, but in the last analysis, all that really matters is reason, argument, and evidence. Somewhere in the middle of this debate are those who maintain that strictly scientific considerations are important in science but so are extrascientific beliefs. For instance, statements of basic metaphysical principles may not be strictly a part of science, yet they have frequently influenced the course of scientific development. Religious, socioeconomic, and other beliefs have also played important roles in science. Even though the line between scientific and extrascientific beliefs is not sharp, as beliefs they are at least cognitive factors. Certain authors, however, argue that extracognitive factors also affect scientific development. In the extreme, they claim that the course of science is determined primarily by socioeconomic causes, such as the French Revolution and the rise of the mercantile middle class. On this view, conceptual development is not a function of beliefs, even socioeconomic beliefs, but of noncognitive causes (*1*, *2*).

Typically, such disputes are carried on in the abstract. Anecdotes and casual impressions pass for evidence. In fact, the idea that such disputes might actually be settled by recourse to evidence hardly seems to have occurred to those engaged in them (*3*). The purpose of this article is to test two widely held opinions about one particular episode in the history of science. The episode is the Darwinian revolution in Great Britain. The opinions are that younger scientists were converted much more quickly than older scientists, and that among scientists Darwin triumphed rapidly and totally. In 1863 Kingsley (*4*) remarked that the "state of the scientific mind is most curious; Darwin is conquering everywhere, and rushing in like a flood, by the mere force of truth and fact." In 1870 Bennett (*5*) noted that the "fascinating hypothesis of Darwinism has, within the last few years, so completely taken hold of the scientific mind, both in this country and in Germany, that almost the whole of our rising men of science may be classed as belonging to this school of thought." In the first part of this article we show that both of these views were widely held in Darwin's day and continue to be accepted by historians of science to the present. We then proceed to test them by discovering how rapidly scientists actually did come to accept the evolution of species, and whether age actually did make a difference.

At the outset, these two beliefs about the Darwinian revolution pose a certain problem for each other. If scientific change must wait for old scientists to die off and be replaced by a new generation and if the Darwinian flood was as rapid and as total as its Mosaic counterpart, then soon after 1859 the mortality rate of Victorian scientists must have taken an alarming leap. Needless to say, it did not. Our reliance on data to help resolve the dispute over the relative importance of external and internal considerations in scientific development also poses a problem for us. It commits us to some form of internalism. After all, if we did not think that evidence has some influence, we would not have bothered to gather it. If all beliefs are determined in the long run by socioeconomic beliefs or socioeconomic causes, then beliefs on this particular issue will be determined by the same considerations. Recourse to scientific rigor is just empty show, designed to appeal to the prejudices of those who have deluded themselves into thinking that evidence matters. Thus, the design of our study automatically precludes our accepting extreme externalism. This limitation is not as serious as it might seem because few, if any, authors have openly opted for pure externalism—or pure internalism for that matter. The real issue is which factors have actually been operative in particular cases and how important each has been. Our study is designed to answer this question with respect to one factor—age—for one episode in the history of science—the Darwinian revolution.

The distinction between reasons and causes is not an easy one to make, even in principle. In practice it is often even more difficult. A scientist's age, for example, may function either as a noncognitive factor in scientific change or as an index of a variety of cognitive factors. If hardening of a scientist's arteries precludes understanding and acceptance of a new scientific idea, then age is functioning as a noncognitive cause. Of course, older scientists may simply know much more than their younger colleagues and see more of the ramifications of a new idea. Realizing the extent to which Darwin's views negated the science of one's day might be a function of age, but it nevertheless is exactly the sort of cognitive factor that internalists claim is so important in science. Or possibly the older scientist's own career is more intimately connected to the views being challenged. Rejecting a new idea because it threatens one's position in the scientific community is a reason, but it is not the sort of scientific reason that inter-

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nalists like to think affects the course of science significantly. If age turns out to be correlated with rapidity of acceptance of new scientific ideas, then the various possible explanations for this correlation must be teased apart and examined. However, if no correlation can be found, then doubt is cast on age both as a noncognitive cause and as an index of something else.

Planck's Principle

In his autobiography, Planck (*6*) remarks that a "new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it." If Planck is right, reason, argument, and evidence do not play a very large role in scientific change. Each generation of scientists is raised in a particular orthodoxy and, once indoctrinated, cannot be converted. The death rate of scientists sets an upper limit to the rate of scientific change. One might think that scientists would find such a view repugnant, but time and again scientists can be found making equally cynical remarks about the inability of other scientists, especially older scientists, to change their minds. For example, Lavoisier (*7*) ends his *Reflections on Phlogiston* as follows:

> I do not expect my ideas to be adopted all at once. The human mind gets creased into a way of seeing things. Those who have envisaged nature according to a certain point of view during much of their career, rise only with difficulty to new ideas. It is the passage of time, therefore, which must confirm or destroy the opinions I have presented. Meanwhile, I observe with great satisfaction that the young people are beginning to study the science without prejudice, and also the mathematicians and physicists, who come to chemical truths with a fresh mind—all these no longer believe in phlogiston in Stahl's sense.

Near the end of the *Origin of Species*, Darwin (*8*) makes a similar remark:

> Although I am fully convinced of the truth of the views given in this volume under the form of an abstract, I by no means expect to convince experienced naturalists whose minds are stocked with a multitude of facts all viewed, during a long course of years, from a point of view directly opposite to mine. It is so easy to hide our ignorance under such expressions as the "plan of creation," "unity of design," &c., and to think that we give an explanation when we only restate a fact. Any one whose disposition leads him to attach more weight to unexplained difficulties than to the explanation of a certain number of facts will certainly reject my theory. A few naturalists, endowed with much flexibility of mind, and who have already begun to doubt on the immutability of species, may be influenced by this volume; but I look with confidence to the future, to young and rising naturalists, who will be able to view both sides of the question with impartiality.

T. H. Huxley was so convinced of the inability of older scientists to change their minds that he declared that men of science ought to be strangled on their 60th birthday "lest age should harden them against the reception of new truths, and make them into clogs upon progress, the worse, in proportion to the influence they had deservedly won" (*9*). Needless to say, Huxley took considerable ribbing when he himself turned 60.

Numerous present-day philosophers, historians, and sociologists can be found agreeing that age makes a difference in the alacrity with which scientists change their minds. For example, both Kuhn (*10*) and Feyerabend (*11*) quote Planck's principle in support of their thesis that scientific revolutions are, at bottom, arational affairs. Although Kuhn notes that facts such as these need further reevaluation, he believes that they are "too commonly known to need further emphasis." J. Cole and S. Cole (*12*) quote Planck's principle in connection with the "gradual replacement of older elites with younger men who may hold new ideas about the conceptual framework of their discipline." Although Cantor (*2*, p. 196) acknowledges counterexamples, he concludes that "incommensurability tends to confirm Planck's statement." Bondi (*13*) finds Planck's principle an "uncomfortable statement, but perhaps not a wholly incorrect one." In his discussion of the social and cultural sources of resistance to scientific change, Barber (*14*) mentions Planck's principle but does not pursue it. As balanced as Barber's assessment is, the overall impression it gives is that scientists are not as open-minded as they profess to be. Merton (*15*) goes one step further. Not only are scientists resistant to change, but also this resistance plays a positive role in scientific change. Without it, science would be inundated with half-baked ideas.

Numerous authors have also commented specifically about the role of young scientists in the success of Darwin's theory and the reticence of older scientists. For example, Gunther (*16*) states that the "older generation, steeped in the Bible, rejected the theory with a sense of shock." Paul (*17, 18*) notes how difficult it was for the Italian clerical intelligentsia to hold onto the old scientific dogmas as the "generation of anti-Darwinian scientists died and the new biological community accepted, however critically, more and more Darwinistic dogmas." Loewenberg (*19*) remarks that "Darwin's characteristic perspicacity is nowhere better illustrated than in his prophesy of the reaction of the world of science." Older scientists were all but impossible to convert. Only younger scientists had sufficient flexibility of mind to understand and accept evolutionary theory. Although Hagstrom (*20*) warns that it would be "just as unwise to accept the statements by Darwin and Planck without question as it would be to accept the statements of Robespierre and Lenin about their opponents in revolutions of another kind," he thinks there is enough to the phenomenon to suggest an explanation:

> Young scientists may find it easier to accept new views than old scientists, who may be more strongly committed to the earlier views. Although young scientists have been subjected to an education in which they are indoctrinated with accepted theories and seldom given any arguments against them, the commitments they make may be superficial. Firm commitments to a theory may be achieved only by those who have used it to account for things previously inexplicable, who have experienced the range of its power and the difficulties of subjecting it to test. Given a crisis or an innovation, the older generation may firmly believe in the possibility of reconciling it with established theory. Younger scientists, on the other hand, will perceive most clearly the incompatibility of innovations and existing theory.

Certainly the claim that well-stocked minds should be more difficult to change than those that are all but empty sounds plausible enough. Certainly, mature scientists should be more committed to received views than young scientists just starting on their careers. However, little in the way of empirical evidence has been presented to show that the phenomenon even exists. Few claims about noncognitive influences on science lend themselves to empirical testing. The nice thing about Planck's principle is that it does. It is easy to find out when 19th-century scientists were born and died—more difficult, although not impossible, to discover when they came to adopt various positions on scientific issues, and then to compare the two. If the authors cited in this section are right, budding young scientists in 1859 should have been the easiest to convert to a belief in the evolution of species, old codgers all but intransigent.

The Darwinian Flood

In Darwin's day the general opinion was that within 10 years or so after the appearance of the *Origin of Species*,

Darwin had triumphed. Thomas's comment (*21*) in his 1877 presidential address to the British Association for the Advancement of Science was typical. He observed that Darwinism had "secured, in the incredibly short space of ten or twelve years, the general approval of a large portion of the scientific world." The choice of the 10-year period is especially fitting because that was the time allotted for the demise of evolutionary theory by Richard Owen, a prediction that especially rankled Darwin. Owen further irritated Darwin by simultaneously rejecting Darwin's views while claiming priority for them (*22*).

The 10-year period is also popular among recent commentators on the Darwinian revolution. For example, Himmelfarb (*23*) concludes, "It was, in fact, not in his lifetime but in a single decade that Darwin saw his ideas triumph." Darlington (*24*) agrees: "In about 10 years' time, however, the educated world was effectively converted to Darwin's view of what had come to be called evolution and was now called Darwinism." Ellegård (*25*), one of the rare authors who actually performed the sort of wide sampling necessary to justify such claims, also concludes that in Great Britain, at least, the "establishment of an evolutionary view had been virtually achieved among the educated classes before the end of the first decade after the publication of the *Origin of Species*."

Was evolutionary theory more popular among scientists than the educated public? Among scientists themselves, were scientists in certain disciplines more strongly disposed to it than those in other fields? Were all parts of Darwin's theory equally popular? Was the fate of Darwinism the same throughout the scientific world? Little work has been done in attempting to answer such questions. Ellegård's study of the reactions published in the British popular press is one exception. Another is a volume conceived and edited by Glick (*18*) in which a dozen or so historians compare the reception of Darwinism around the world. In most countries, these authors found the triumph of Darwinism to be rapid and almost total. For instance, Paul (*26*) discovered rapid, "nearly universal acceptance of Darwinism by the Italian scientific community." Montgomery (*27*) observed that the battle against Darwinism in Germany was "essentially lost by the end of the decade," although "some opponents were still active in the 1870's." Bulhof (*28*) noted, "Especially among the younger scientists, the Darwinian theory of an evolution of the species quickly changed in status from a daring hypothesis to an undisputed fact." The transition to the Darwinian world view proceeded "in a remarkably fast tempo, which cannot be explained by the state of scientific theory in the Netherlands around 1859 alone."

In spite of the religious climate in the United States and the opposition of the formidable Louis Agassiz, the victory of evolution in America was just as total and almost as rapid as it had been in Italy, Germany, and the Netherlands. Although Agassiz remained firmly antievolution until his death, J. D. Dana, the second most powerful naturalist in the United States at the time, capitulated in 1874. Although none of the presidents of the "best schools" in the United States would admit that evolution was being taught in their classrooms, the *Presbyterian Observer*, when challenged in 1880 by the *Popular Science Monthly*, could find only one American naturalist who would publicly repudiate evolutionary theory (*29*). In spite of the power exercised by the Catholic Church in Spain, Glick (*30*) concluded that even in Spain, the "permeation of evolutionary ideas was so pervasive that Catholic revanchism was unable to roll back the tide." Change was not so rapid, nor so total, in tzarist Russia and in France. Well-established scientists in Russia held firm in their old beliefs, and the young advocates of evolution had to seek employment elsewhere (*31*). Of all the nations in the world that could claim a scientific tradition at the time, France proved to be the most immune to Darwinism (*32*).

Scope of the Study

By investigating the published pronouncements and private correspondence of British scientists who were at least 20 years of age in 1859 and lived at least until 1869, we have attempted to assess how successful Darwin was in converting the scientific community in Great Britain to a belief in the evolution of species, and the role that age played in the alacrity with which scientists changed their minds on the subject. Each of the limitations in the scope of our study calls for some comment. An accurate and extensive sampling of scientists around the world was out of the question. Some narrowing of scope was necessary. Great Britain was the obvious choice. Darwin was British, the reception of evolutionary theory has been documented more completely for Great Britain than for any other country, and the literature was most readily available. Of course, the reaction of British scientists may be peculiar. As we have already noted. Planck's principle seems to apply to the situation in Russia. Few, if any, well-established scientists were converted. It does not apply in France but for the opposite reason. French scientists, young and old alike, seemed impervious to the charms of Darwinism.

Because Planck's principle refers to scientists, we have limited our study to scientists as they were conceived at the time. The distinction between scientists and nonscientists was hazier in Victorian England than it is today. It was also drawn along somewhat different lines. In the middle of the 19th century, the professionalization of science was only just getting under way in Great Britain. The best universities did not offer degrees in the natural sciences, few posts were open to professional scientists, and scientific organizations were still open to amateurs and royal patrons. When there was any doubt about the status of a subject as a scientist, we tended to cast our net too broadly rather than too narrowly (*33*). Our study also tends to be most heavily weighted toward the sciences that touched most directly on the question of the evolution of species; that is, zoology, botany, paleontology, geology, and anthropology. Because of the conflict between Darwin and Lord Kelvin over the age of the earth, a few physicists also made their views known.

The age limitations are equally important. We selected a lower limit of 20 in 1859 both to guarantee that the scientist would have assimilated at least a little of the special creationist world view before being confronted by Darwin's theory and to exclude scientists who were children at the time. Certainly Edwin Ray Lankester (1847–1929) and Edward B. Poulton (1856–1943) were important Darwinists, but not because they were converted to the view. They were raised Darwinists. Ten years was chosen because of the widespread opinion that by then the battle was over. Anyone who lived through that period and still was not won over can legitimately be counted among those who were difficult to convert.

Intellectually, science is extremely elitist. As sociologists of science have shown time and again, a very few scientists produce most of the major innovations (*3, 12, 15*). If their behavior is any indication, scientists do not seem overly concerned with the opinions of ordinary, run-of-the-mill scientists. Instead, they seem to be most interested in converting the big guns. Darwin was no exception. He consciously set out to persuade important, well-placed scientists both before he published his *Origin*

Table 1. Age in 1859 of scientists who accepted the evolution of species within 10 years of the publication of Darwin's *Origin of Species* compared to their age at acceptance and the age in 1869 of those who did not accept evolution.

Name and dates	Age in 1859	Age at earliest evidence of acceptance	Age in 1869 of continued rejectors
Babington, C. C. (1808–1895)	51		61
Balfour, J. H. (1808–1884)	51		61
Bastian, H. C. (1837–1915)	22	32	
Bates, H. W. (1835–1892)	34	32	
Bell, T. (1792–1880)	67		77
Bennett, A. W. (1833–1902)	26	36	
Bentham, G. (1800–1884)	59	63	
Busk, G. (1807–1886)	52	54	
Butler, A. G. (1831–1909)	28	38	
Carpenter, W. B. (1813–1885)	46	47	
Duncan, P. M. (1821–1891)	38	44	
Fawcett, H. (1833–1884)	26	27	
Flower, W. H. (1831–1899)	28	29	
Frankland, E. (1825–1899)	34	39	
Galton, F. (1822–1911)	37	38	
Geikie, A. (1835–1924)	24	24	
Gosse, P. H. (1810–1888)	49		59
Gray, J. E. (1800–1875)	59		69
Grove, W. R. (1811–1896)	48	55	
Günther, A. C. L. (1830–1914)	29		39
Haughton, S. (1821–1897)	38		48
Herschel, J. F. W. (1792–1871)	67	69	
Hirst, T. A. (1830–1892)	29	34	
Holland, H. (1788–1873)	71	72	
Hooker, J. D. (1817–1911)	42	41	
Humphrey, G. M. (1820–1896)	39	46	
Hunt, J. (1833–1869)	26		36
Hutton, F. W. (1836–1905)	23	33	
Huxley, T. H. (1825–1895)	34	34	
Jardine, W. (1800–1874)	59		69
Jeffreys, J. (1809–1885)	50	59	
Jenkin, F. (1833–1885)	26		36
Jenyns, L. (1800–1893)	59	60	
Jevons, W. S. (1835–1882)	24	34	
Jukes, J. B. (1811–1869)	48	49	
Kingsley, C. (1819–1875)	40	44	
Lankester, E. (1814–1874)	45	55	
Lewes, G. H. (1817–1878)	42	51	
Lubbock, J. (1834–1913)	25	26	
Lyell, C. (1797–1875)	62	70	
M'Intosh, W. C. (1838–1931)	21		31
Mivart, G. J. (1827–1900)	32	33	
Mill, J. S. (1806–1873)	53		63
Molesworth, W. N. (1816–1890)	43	46	
Morris, F. O. (1810–1893)	49		59
Murchison, R. I. (1792–1871)	67		77
Murray, A. (1812–1878)	47	56	
Newton, A. (1829–1907)	30	31	
Page, D. (1814–1879)	45	50	
Phillipps, J. (1800–1874)	59		69
Ramsey, A. C. (1814–1891)	45	46	
Rolleston, G. (1829–1881)	30	31	
Sclater, P. L. (1829–1913)	30	31	
Scott, J. G. (1838–1880)	21	26	
Sedgwick, A. (1785–1873)	74		84
Spottiswoode, W. (1825–1883)	34	39	
Stokes, G. G. (1819–1903)	40		50
Tegetmeier, W. B. (1816–1912)	43	43	
Thomson, C. W. (1830–1882)	29	38	
Thomson, W. (1824–1907)	35	45	
Thompson, A. (1809–1884)	50	60	
Thwaites, G. H. K. (1811–1882)	48	49	
Tristam, H. B. (1822–1906)	37	37	
Tyndall, J. (1820–1893)	39	44	
Watson, H. C. (1804–1881)	55	56	
Wood, S. V. (1798–1880)	61	62	
Young, John (1835–1902)	24	31	

of Species and after. He was interested primarily in the verdict of a dozen or so men of science. If they came around, the rest would follow (*22*, vol. 1, pp. 521 and 529). This attitude probably explains in part the cynicism expressed in retrospect by scientists who succeeded in revolutionizing the science of their day about the inability of older scientists to change their minds. They are not reacting to the behavior of older scientists in general, but to the behavior of the scientists whose opinions mattered to them.

Although we did not limit ourselves just to "important" scientists in our study, our results are surely biased in that direction because of the availability of evidence. Because Darwinism succeeded, young Darwinists left much more in the way of records than did young anti-Darwinists. Young scientists were successful to some extent because they became Darwinists, and the views of successful scientists are much easier to document than those of the failures. For example, in April 1864 a group of London chemists circulated a "Declaration of Students of the Natural and Physical Sciences" among their fellow scientists for signature. The document declared that scientific investigations could not possibly contradict Holy Scripture. When a scientist finds that "some of his results appear to be in contradiction to the Written Word," he "should not presumptuously affirm that his own conclusions must be right, and the statements of Scripture wrong" (*34*). The ages of the six authors of this declaration in 1864 were 21, 23, 23, 25, 25, and 55. The authors of this declaration as well as the more than 700 scientists who signed it would seem to be excellent candidates for scientists opposed to the evolution of species. Unfortunately, most of the signators are so obscure that no evidence could be found for them. If any group is underrepresented in our survey, it is surely young scientists opposed to the evolution of species.

The greatest difficulty that confronted us in our study was deciding what was to count as Darwinism. Because the Darwinian revolution is named after Charles Darwin and seemed to have begun soon after the publication of the *Origin of Species* in 1859, one is tempted to assume that Darwin and his ideas played a central role in the controversy. To be counted as a convert to Darwinism, one might think that a scientist would have to adopt Darwin's ideas, or most of Darwin's ideas, or at least his essential ideas. However, very few scientists in the second half of the 19th century ac-

Table 2. Victorian scientists who accepted some form of the evolution of species independently of the work of Darwin and Wallace.

Name and dates	Date	Age
Chambers, R. (1802-1871)	1844	42
Croll, J. (1821-1890)	1848	27
Grant, R. E. (1793-1874)	1851	58
Matthew, P. (1790-1874)	1831	41
Powell, B. (1796-1860)	1845	49
Spencer, H. (1820-1903)	1840	20

cepted evolutionary theory as Darwin set it out. Darwin believed that evolution occurred gradually. The variations that were operative in the evolutionary process were very small, although not "continuous" (*35*), and occurred in "all directions." Although Darwin believed that occasionally an acquired character could be transmitted to an organism's progeny, the chief directive force in evolution was natural selection. (Whether Darwin considered sexual selection a special form of natural selection or a distinct directive force is a moot question.) However, the view of evolution that was popular among scientists in the second half of the 19th century was saltative, directed, and progressive. Huxley, for example, opted for saltative evolution, the origin of a new species in the space of a single generation. Asa Gray, another of Darwin's most able supporters, argued for directed, progressive evolution. Some of Darwin's most bitter opponents held precisely the same views as his allies such as Saint George Jackson Mivart.

If a scientist must accept everything that Darwin said with respect to the origin of species to count as a Darwinist, then there were few Darwinists in the 19th century (*36*). If, on the other hand, all it took to be an advocate of Darwinism was to accept a bit here and there, then nearly everyone was a Darwinist. As Leeds (*37*) notes with some dismay:

> What appears to me striking is how few of the figures discussed in these pages—with the exception of a small number of the Spanish, the Germans, and the English—held a Darwinian view at all. Mostly they assimilated a phrase or an aspect of Darwin's expression of his thought to their own understanding and thought, then, that they were Darwinians. The most striking case is that of the Russians, discussed in James Allen Rogers' paper, in which *not one* of the protagonists of his drama is remotely near the Darwinian model.

Thus, neither the primary nor the secondary literature can be taken at face value. Two scientists could hold exactly the same views and one term himself a disciple of Darwin and the other a staunch opponent. Of all the elements of Darwinism, we have chosen just one to follow—Darwin's claim that species evolve. Although this element of Darwinism was the least original with Darwin, it was his chief concern and the element that supposedly became most widely accepted in his day (*38*). It was this belief that swept across the scientific communities of the world like the flood. Scientists may have come to accept the evolution of species because Darwin set out his views in a scientifically respectable way and because he suggested a naturalistic mechanism for such transformations, but paradoxically, if we are to believe the secondary literature, they did *not* accept natural selection (*39*). If we had selected some other element in the Darwinian research program to investigate, the results might have been different. For example, Darwin thought that use and disuse might have some effect on later generations, a belief that was widespread at the time. Darwin would have had few scientists to convert. Conversely, if we had selected natural selection instead of evolution, Darwin would have been much less successful. The fates of the various elements in Darwin's theory differ. The relevant issue for our purposes is, however, whether or not these differences in acceptance covary with differences in the ages of the scientists involved.

Methods and Results

We were able to gather sufficient data for 67 British scientists who were at least 20 in 1859 and lived until at least 1869 (Table 1). Our search began with the members of the Royal Society whom Francis Galton deemed genuine scientists and proceeded to scientists mentioned in the secondary literature dealing with Victorian science (*40*). Thereafter our search was largely a random walk. Scientists such as Herbert Spencer and Robert Chambers, who came to believe in the evolution of species independently of Darwin and Wallace, are not included in our study (Table 2). However, we have included two scientists converted by Wallace and Darwin before 1859. Wallace convinced H. W. Bates in 1857, and Darwin was able to persuade J. D. Hooker a year later. (If evolution was so much "in the air," why was Darwin able to convince only one of the dozen or so scientists with whom he discussed his theory before the appearance of the *Origin*?)

In order to be classed among the converted, a scientist had to state explicitly that he believed in the evolution of species—that is, that species arose by means of one species changing through time into another. Whether he believed that evolution was directed or undirected, progressive or nonprogressive, saltative or gradual is irrelevant, as is the subject's beliefs about spontaneous generation and natural selection. A statement to the effect that the author opposed Darwinism lacks sufficient information to be of any use. It could mean anything. Many anti-Darwinists accepted the evolution of species. However, we found no instance in which someone professed to be a Darwinian and yet did not accept at least the claim that species evolve.

Table 3. Specialties of scientists who continued to reject the evolution of species in 1869.

Name	Specialty
Babington, C. C.	Botany
Balfour, J. H.	Botany
Bell, T.	Zoology
Gosse, P. H.	Marine biology
Gray, J. E.	Zoology (Mollusca)
Günther, A. C. L.	Zoology (reptiles)
Haughton, S.	Mathematics and geology
Hunt, J.	Anthropology
Jardine, W.	Zoology (ornithology)
Jenkin, F.	Engineering
M'Intosh, W. C.	Zoology (marine annelids)
Mill, J. S.	Philosophy and economy
Morris, F. O.	Zoology
Murchison, R. I.	Paleontology
Phillips, J.	Geology
Sedgwick, A.	Geology
Stokes, G. G.	Physics and mathematics

The first feature of our data worth noting is that only 50 of the 67 scientists studied (less than three-quarters) had come to accept the evolution of species by 1869. Thus, although the conversion of the scientific community in Great Britain was certainly extensive, it was neither universal nor nearly so. If only 75 percent of the scientists at the time accepted the most widely accepted of all the elements in Darwin's theory, then the conversion of the British scientific community was not nearly as rapid nor as total as we have been led to believe. The question remains why Darwinism seemed at the time and in retrospect to be more successful than it actually was. Although our sample is too small to tell, field of interest also did not seem to have much effect. The same spectrum of fields can be found among those who accepted the evolution of species as those who rejected it (Table 3).

If Planck's principle is correct, scientists who came to accept the evolution of species before 1869 should have been significantly younger than those who

Table 4. Views on evolution of scientists who died between 1859 and 1869.

Name and dates	Age in 1859	Date of acceptance	Age at acceptance	Age at death
Boott, F. (1792-1863)	67	1860	68	71
Brewster, D. (1781-1868)	78			87
Crawfurd, J. (1783-1868)	76			85
Daubény, C. G. (1795-1867)	64	1860	65	72
Falconer, H. (1809-1865)	50	1863	54	56
Harvey, W. H. (1811-1866)	48	1860	49	55
Henslow, J. S. (1796-1861)	63			65
Hopkins, W. (1793-1866)	66			73
Horner, L. (1785-1864)	74	1861	76	79
Rogers, H. D. (1809-1866)	51	1860	52	57
Whewell, W. (1794-1866)	65			72

continued to hold out. Furthermore, of those who accepted evolution, the younger scientists should have been converted much more quickly than the older scientists. We used two methods to test the merits of Planck's principle: first, a simple comparison of the average age in 1859 of accepters and rejecters, and, second, the logit technique (*41*) to obtain an unbiased estimate of the coefficient of age when acceptance is regressed on age. Both methods were applied first on the data that excluded those who died between 1859 and 1869 and then on the data that included this information (Table 4). In our basic sample, the average age of accepters was 39.6 and that of rejecters was 48.1, a difference of almost 10 years (*42*). When a two-tailed t-test was performed, the t-statistic was 2.256, indicating that the difference in mean age is statistically significant at $P < .05$. We obtained similar results when we added to our sample scientists who had died between 1859 and 1869. For this larger sample, the mean age of accepters rose to 41.7 and the age of rejecters increased to 53.0. The t-statistic was 3.071, significant once again at $P < .05$. Thus, age is a relevant factor in distinguishing between those scientists who accepted the evolution of species before 1869 and those who did not.

Next we used the logit technique to obtain the coefficient on year of birth when acceptance is regressed on year of birth. In the equation

$$A = \alpha + \gamma B$$

A is a dummy variable equal to 1 if the scientist accepted evolution before 1869 and 0 if he did not; α is the estimated constant; B is the year of birth of the scientist; and γ is the estimated coefficient that minimizes the error in predicting A. Using our basic sample, the estimated value of γ is 0.046 with a t-statistic of 2.159. As in the case of our first method, enlarging the basic sample to include scientists who died between 1859 and 1869 does not change the results much. The estimated γ is 0.051 with a t-statistic of 2.791. Once again, age makes a difference. In predicting acceptance, year of birth is significant at $P < .05$. However, the R^2 (the square of the correlation coefficient) for the regression on our basic data is .06, which means that less than 10 percent of the variation in acceptance is explained by age.

Planck's principle also implies that of scientists who accepted the evolution of species before 1869, younger scientists should have changed their minds more quickly than older scientists. To test this hypothesis, we regressed years of delay on age in 1859. The coefficient obtained was −0.052 with a t-statistic of −1.193. When scientists who died between 1859 and 1869 were added to the sample, the coefficient became −0.064 and the t-statistic −1.796. Thus, in neither case does age seem to matter. Of the scientists who accepted the evolution of species before 1869, older scientists were as quick to change their minds as younger scientists.

Conclusion

The results of this study indicate that our intuitions about the course of science, although not totally faulty, are none too reliable. Darwin and his contemporaries thought that nearly all scientists had come to accept the evolution of species within 10 years after the publication of the *Origin*. They also thought that younger scientists with their more "plastic" minds were easier to convert than older scientists. Later commentators, looking back at this period, have gathered this same impression. To be sure, the scientists who still refused after 1869 to admit that species evolve were significantly older than those who jumped on the Darwinian bandwagon. However, age explains less than 10 percent of the variation in acceptance. More than 90 percent remains to be explained. The possibility exists that at least some of this variation can be explained in terms of the efficacy of reason, argument, and evidence. It should also be noted that 25 percent of the scientists in our study remained unconvinced in 1869, and that when the ages of the scientists who did come to accept the evolution of species in this period were compared to the time it took them to be converted, no significant correlation materialized.

Most scientific theories fail. The issue about the relation between the age of scientists and the spread of new scientific ideas arises only for theories that, in retrospect, we think scientists should have accepted. No one complains that the scientific community remained impervious to phrenology, mesmerism, and the flat earth movement. In the case of successful scientific research programs, a new idea becomes increasingly accepted. During the same period, older scientists are dying off at a higher rate than younger scientists. Because these two processes are taking place at the same time, we are led to suspect a causal connection. Clearly the spread of new scientific ideas rarely causes scientists to die. The question remains whether the death of scientists facilitates the spread of new scientific ideas. If we had studied a theory that gained some converts and then disappeared—that is, if we had studied the usual case—our figures might have been quite different. Our study does not show that Darwin conquered everywhere "by mere force of truth and fact," but it does show that the connection between age and acceptance is not as important as people such as Max Planck have claimed.

References and Notes

1. For an example of a debate over the role of cognitive and noncognitive factors in science with special reference to phrenology, see G. N. Cantor (*2*); *Ann. Sci.* **32**, 245 (1975); S. Shapin, *ibid.*, p. 219.
2. G. N. Cantor, *ibid.*, p. 195.
3. As early as 1949, N. Pastore [*The Nature-Nurture Controversy* (Columbia Univ. Press, New York, 1949)] compared the views of 24 biologists on the nature-nurture issue with their political persuasion. He found that 11 out of 12 conservatives favored nature while 11 out of 12 liberals and radicals opted for nurture as the major influence. S. Cole [in *The Idea of Social Structure*, L. A. Coser, Ed. (Harcourt Brace Jovanovich, New York, 1975), p. 175] has actually set about testing some of the claims made by philosophers about science. One of the claims that he lists as needing empirical support is Planck's principle (p. 181).
4. C. Kingsley, *Charles Kingsley, His Letters and Memories of His Life* (Macmillan, London, 1890), p. 253.
5. A. W. Bennett, *Nature (London)* **3**, 30 (1870).
6. M. Planck, *Scientific Autobiography and Other Papers* (Williams & Norgate, London, 1950), pp. 33-34.
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Huxley (Appleton, New York, 1901), vol. 2, p. 117.
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13. H. Bondi, in *Problems of Scientific Revolution*, R. Harre, Ed. (Clarendon, Oxford, 1975), p. 7.
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15. R. K. Merton, *The Sociology of Science* (Univ. of Chicago Press, Chicago, 1973), pp. 497–559.
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17. H. W. Paul, in (*18*), p. 412.
18. T. F. Glick, Ed., *The Comparative Reception of Darwinism* (Univ. of Texas Press, Austin, 1974).
19. B. Loewenberg, *Am. Hist. Rev.* **38**, 687 (1932).
20. W. O. Hagstrom, *The Scientific Community* (Basic Books, New York, 1965), pp. 283–284.
21. A. Thomas, in *Victorian Science*, G. Basalla, W. Coleman, R. H. Kargon, Eds. (Doubleday, Garden City, N.Y., 1970), p. 205.
22. F. Darwin, *The Life and Letters of Charles Darwin* (Appleton, New York, 1899), vol. 2, pp. 85 and 117. We omitted Owen's name from our study because we were unable to decide what his views were on the origin of species.
23. G. Himmelfarb, *Darwin and the Darwinian Revolution* (Doubleday, Garden City, N.Y., 1959), p. 252; see also (*16*), p. 453.
24. C. D. Darlington, *Sci. Am.* **200**, 60 (May 1959).
25. A. Ellegård, *Darwin and the General Reader* (Gothenburg Univ., Gothenburg, Sweden, 1958), p. 337.
26. H. W. Paul, in (*18*), p. 409.
27. W. Montgomery, in (*18*), p. 91; see also (*42*).
28. I. Bulhof, in (*18*), p. 284.
29. E. Pfeifer, in (*18*), p. 204.
30. T. Glick, in (*18*), p. 310.
31. A. Vucinich and J. A. Rogers, in (*18*), pp. 227–268.
32. R. E. Stebbins, in (*18*), pp. 117–163.
33. Francis Galton was presented with the same problem when he undertook the first sociological study of scientists in Great Britain. His solution was to restrict his sample to the members of the Royal Society who had distinguished themselves in some way other than just being elected to the Society; for instance, by earning a medal, presiding over a learned society or section of the British Association for the Advancement of Science, or being elected to the council of the Society. Of the 500 or so members in 1872, only 189 qualified. To this number, Galton added Herbert Spencer, John S. Henslow, and Robert H. Greg [F. Galton, *English Men of Science: Their Nature and Nurture* (Macmillan, London, 1874)].
34. W. H. Brock and R. Macleod, *Br. J. Hist. Sci.* **11**, 41 (1976). The declaration had been signed by 717 scientists when it was finally published in 1865. Sixty-five of the 673 members of the Royal Society signed. Of these, 48 were considered to be sufficiently important scientists to be labeled as such in the *Dictionary of National Biography*. Of these, only three were especially prominent scientists: Sir David Brewster (1781–1868), James Prescott Joule (1818–1889), and Adam Sedgwick (1785–1873). Of special relevance to our study is Brock and Macleod's conclusion that age seemed to be immaterial in determining who signed and who did not sign the declaration (p. 52).
35. D. L. Hull, *Syst. Zool.* **21**, 132 (1972); P. J. Bowler, *Ann. Sci.* **35**, 55 (1978).
36. R. W. Burkhardt, Jr., *Isis* **67**, 494 (1976).
37. A. Leeds, in (*18*), p. 439.
38. As Darwin himself said in the *Athenaeum*, 1854, 617 (1863): "Whether the naturalist believes in the view given by Lamarck, or Geoffroy St.-Hilaire, by the author of the 'Vestiges,' by Mr. Wallace and myself, or in any other such view, signifies extremely little in comparison with the admission that species have descended from other species and have not been created immutable; for he who admits this as a great truth has a wide field opened to him for further inquiry."
39. In this article we show that our intuitions about the role of age in acceptance of the evolution of species and the extent of this acceptance by 1869 are faulty. Hence, we would be foolish to accept at face value the widespread belief that evolution was much more widely accepted than natural selection. For example, in 1913, soon after the fortunes of natural selection were supposed to have reached their lowest ebb, E. R. Lankester [*Science from an Easy Chair* (Books for Libraries Press, Freeport, N.Y., 1913), p. 391] can be found saying: "I recently read an essay in which the writer is good enough to say that, owing to the work of Darwin, the fact that the differences which we see between organisms have been reached by a gradual evolution, is not now disputed. That, at any rate seems to be a solid achievement. But he went on to declare that when we inquire by what method this evolution was brought about biologists can return no answer. That appears to me to be a most extraordinary perversion of the truth. The reason why the gradual evolution of the various kinds of organisms is not now disputed is that Darwin showed the method by which that evolution can and must be brought about. . . . The assertion that the theory of natural selection as left by Darwin 'is now generally held to be inadequate' is fallacious. Darwin's conclusions on this matter are generally held to be essentially true."
40. F. Galton (*33*); in addition to the usual Victorian lives and letters, Ellegård (*25*) and Brock and Macleod (*34*) were especially useful.
41. H. Theil, *Principles of Econometrics* (Wiley, New York, 1971), pp. 628–636.
42. W. Montgomery [in (*18*), p. 115] did a similar study of 34 German scientists in 1860. Although his sample was half as large as ours, his results accord reasonably well with ours. He found the mean age in 1860 of the 20 German scientists who came to accept some form of evolution to be 36.8 and the mean age of the 14 who continued to hold out to be just under 50. In Montgomery's study, only 59 percent of the scientists studied were converted.
43. The research for this article was supported in part by NSF grant Soc 75 03535. We thank A. McHutcheon for help in using the logit technique.

NEWS AND COMMENT

Accident and Hostile Citizens Beset Animal Disease Laboratory

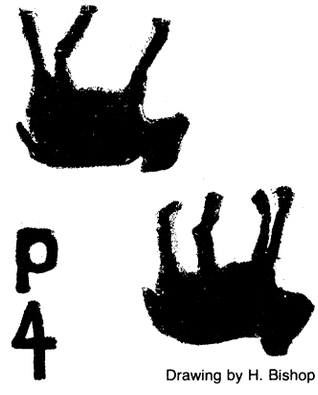
The customarily placid waters around Plum Island, site of the Department of Agriculture's high-security Animal Disease Center, have been ruffled by squalls from two different directions. One is the outbreak of foot-and-mouth disease which occurred in mid-September when the virus escaped from the laboratory and infected cattle being held on the island (*Science*, 20 October). The other is apprehension among the communities on neighboring Long Island about the laboratory's plan to start work with Rift Valley fever, an exotic African disease that has recently become a health menace in Egypt. The still unexplained outbreak of foot-and-mouth has not helped allay the citizenry's concern about Rift Valley fever, particularly since Long Island abounds with the mosquitoes that seem to help spread the disease.

The Rift Valley project has become an election issue. Suffolk County executive John Klein is seeking to have the Department of Agriculture keep state authorities better informed of what goes on at Plum Island. Some 25 citizens' organizations, according to one local critic, oppose the Rift Valley project. The public health authorities of Suffolk County, however, are satisfied that the safety precautions being taken are adequate to contain the disease.

The escape of foot-and-mouth disease virus, the first in the Plum Island laboratory's 24-year history, implies either a failure of equipment or a breach of practice. (The virus did not escape from the island, so the overall safety system cannot be said to have failed.) The virus's route of escape has not been pinpointed but a report now being prepared by the Animal Disease Center suggests that a filter may have failed in the room where infected carcasses were incinerated, or that new construction activity, which penetrated walls and uncovered drain lines, may somehow have been involved.

The incident could not have come at a worse time in the center's efforts to assure Long Island residents of the safety of the Rift Valley fever project. A thought occasionally voiced is that the foot-and-mouth outbreak might have been deliberately engineered. Little credence is given this possibility, although the Inspector General's office of the Department of Agriculture is mounting a separate investigation of the outbreak, doubtless for routine reasons.

Among the laboratory employees on Plum Island a possible source of unhappiness caused by the Rift Valley proj-



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