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On Pathological Science

by James R. Fleming

> Science is a set of rules that keeps the scientists from lying to each other. Breaking these rules is unbecoming to scientists. Society wants science to be good, true, and beautiful. In real life, performance does not always conform to the ideal.
>
> -- Trevor I. Williams[1]

What is Pathological Science?

In 1953, at a colloquium at General Electric's Knolls Research Laboratory, Irving Langmuir, a Nobel Prize winning chemist and longtime G.E. employee presented a seminar on "Pathological Science" or "the science of things that aren't so." As examples of this phenomenon he cited Rene Blondlot's work on N-Rays (1903), the case of Mitogenetic Rays (1923), the Allison Effect (1927), the Davis-Barnes "effect" (1929-1931), J.B. Rhine's work on ESP (1930), and reports of flying saucers (1950s).[2] According to Langmuir, science done at the limits of observation or measurement (precisely where most cutting-edge research is done) could become pathological if the scientists involved make excessive claims for their results. He listed the following characteristics of pathological science[3]:

1. Maximum effect caused by barely detectable intensity;

2. Observations are close to the threshold of detectability. Alternatively, numerous measurements are taken, each with a low statistical significance, while hopeful researchers discard enough undesirable data to make the results look promising; random noise may be converted into apparently meaningful patterns;

3. Claims of great accuracy, sensitivity and specificity;

4. Theory increasingly fantastic and contrary to previous experience;

5. Criticisms met by ad hoc excuses; no matter how sincerely they believe in their results, pathological scientists are really making it up as they go;

6. The ratio of supporters to critics rises to near 50% and falls slowly to zero (oblivion) even if the effect is not disproved;

7. Critics cannot reproduce any part of the alleged effect and the experiment fails in the presence of an outside observer;

8. In the end nothing is salvaged.

The Case of N-Rays

A classical example of pathological science is the case of René Blondlot, who, in 1903 found other emissions coming from his experimental device (a Crookes tube generating X-rays) even after he turned the power down. He named the new emissions N-Rays, and claimed they exhibited many of the characteristics of X-rays. He

also found that they could be emitted, for example, by metals subjected to stress and by living materials. As a phenomenon, they were so elusive they could only be observed by watching for faint flickers on a phosphorescent surface. In 1904 Blondlot and others published about 100 papers on N-rays in the official journal of the French Academy, Comptes rendues. For his discovery, Blondlot even received the academy's Leconte Prize of 20,000 francs and a gold medal. Unfortunately, Blondlot's colleagues around the world could not detect N-rays in their labs. Robert W. Wood, professor of physics at The Johns Hopkins University, an accomplished optical experimenter and debunker of numerous frauds, visited Blondlot's laboratory where he was given a lecture demonstration on N-rays. In the darkened room, Wood secretly removed key parts of the experiment, including the prism of Blondlot's spectroscope, proving that N-rays were the figments of the experimenters' imaginations.[4] In fact the case of N-rays was not a hoax, but represented a true delusion, or mass hallucination. In fact Blondlot pursued his erroneous work on N-rays in part because he relied on confirming results and experimental controls provided by a mécanicien in his laboratory, L. Virtz, who was totally dependent on him for employment.[5] Perhaps the exhilarating pace of physics at the time also colored Blondlot's judgement. Crucial discoveries in radioactivity and X-rays had occurred just a few years before.

According to Langmuir, when you are examining such threshold phenomena in science it means that you don't know, you really don't know, whether you are seeing something important or not. N-

Rays, the Davis-Barnes experiment, and mitogenetic rays all have certain things in common. These are cases where there is no dishonesty involved but where people are tricked into false results by a lack of understanding about what human beings can do to themselves in the way of being led astray by subjective effects, wishful thinking, or threshold interactions. These then may be considered examples of pathological science on the individual level.

What Sorts of Factors May Contribute to Pathological Science?

As the case of N-rays illustrates, Blondlot was not only working at the edge of experimental detectability, he was also working at a time of major breakthroughs in physics and needed a major discovery to boost his career. In such circumstances the following sorts of pressures may lead a scientist or their team into the realm of pathology:

- Priority disputes and pressure to be the first to publish a result.
- This is driven by an insatiable eagerness for fresh ideas in the scientific community, and may be linked to the patentability and profitability of proprietary discoveries.
- It is exacerbated by the relative ease of publishing questionable or speculative results in the hope of later confirmation. If confirmation is not forthcoming, or if disconfirmation is not acknowledged by the originator of the idea, the science is in danger of becoming pathological.

• Career pressure or funding pressure -- the need for a scientist to advance in his or her career, or secure funding for their personal or team efforts -- often requires a major breakthrough, perhaps even a named discovery. Blondlot had a solid but undistinguished career and was in such position when he "discovered" N-rays.

• Prizes, such as the French Academy's, for cutting-edge research, especially for new discoveries of phenomena at the edge of detectability may induce researchers to rush to publish dubious results.

• Group self-deception may reign over a lab or community; hope may lead to delusion and overcome reason.

• The investigator may harbor deep-seated beliefs or fears, perhaps that other teams of researchers or scientists of other nations are conspiring to discredit the results of his or her research.

• Scientists and the public may rely on the credentials of a scientist (e.g. Langmuir's Nobel Prize) rather than on verifiable studies.

• Scientists may violate or circumvent the established standards of evidence (as in the case of cold fusion being presented first to the media. Seemingly authoritative testimony by scientists is often presented by scientists in court and may be used either to establish or discredit a scientific result.[6]

Irving Langmuir's Own Encounter with Pathological Science

Pathological science is by no means limited to esoteric physics experiments done in darkened rooms where the perception of the experimenter may be the source of the deception. In fact at the very same time Langmuir presented his seminar at G.E. on pathological science, he was himself involved in making highly dubious claims for the efficacy of cloud seeding in creating rain, otherwise modifying the weather, and perhaps even altering the climate.[7]

The modern era of weather modification research began in the summer of 1946 at the General Electric Research Laboratory in Schenectady, New York when Vincent Schaefer dropped a block of dry ice into a home freezer unit and, to his surprise, instantly transformed a cold vapor cloud into millions of tiny ice crystals. After some rough calculations, Schaefer tossed six pounds of dry ice out of the window of a rented plane and seeded a cold cloud over Greylock peak in the Berkshires, creating ice crystals and fall streaks of snow.[8] According to Schaefer's laboratory notebook, "It seemed as though [the cloud] almost exploded, the effect was so widespread and rapid. . ."[9] Within a year Bernard Vonnegut of M.I.T. (yes Kurt's brother), who had come to G.E. to count the crystals, discovered that silver iodide smoke also "seeded" supercooled clouds. Completing the cloud seeding triumvirate at G.E. was Langmuir, senior scientist and an outspoken, enthusiastic promoter and popularizer of large-scale weather control.[10] In the press and before the meteorological

community, Langmuir expounded his sensational vision of large-scale weather control: of the arid Southwest being changed into fertile farmland and of cloud seeding preventing "all ice storms, all storms of freezing rain, and icing conditions in clouds."[11]

Cloud seeding, however, was becoming a controversial issue and Langmuir's exaggerated claims threatened to take General Electric into litigious territory, far beyond the limits of normal corporate support for research.[12] As newspapers and magazines began to bring the subject of "weather control" to the public's attention, G.E. lawyers tried repeatedly to limit Langmuir's contact with the media and temper his optimistic predictions. Langmuir, however, enjoyed the publicity and collected clippings of his interviews. When one of the G.E. experiments coincided with an eight-inch snowfall in upstate New York, Langmuir was quick to claim that cloud seeding had "triggered" the storm. He further claimed that "chain reactions" could be set off in warm cumulus clouds, that in one field trial a hurricane had changed direction within six hours because of seeding, and that in general all meteorologists needed to do was find the proper "trigger" to release the immense amounts of energy stored in the atmosphere. He even appeared on TV on Dave Garroway's "Today Show" to explain how cloud seeding might prevent hurricane disasters.[13] Perhaps Langmuir's most fantastic claim was that changes in the weather across the continent had been caused by a single silver iodide generator in New Mexico.[14] Langmuir "proved" his result, at least to himself, using an unconventional statistical method of his own devising.

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Undaunted by the concerns of the G.E. legal staff, Langmuir continued to make claims for weather control which could not be substantiated by other meteorologists. Storms of controversy raged for years between Langmuir and the U.S. Weather Bureau. Although skeptical of his results, the meteorological community had no one of the scientific stature of Langmuir to counter his fantastic claims.[15]

Pseudo-science, Hoax, and Fraud

While the practitioners of pathological science, at least as Langmuir defined it, may completely sincere in their delusions, that can not be said for the pseudo-scientific perpetrators of hoax and fraud.[16] For example, L. Ron Hubbard's Dianetics, Immanuel Velikovsky's Worlds in Collision, and Erich von Daniken's Erinnerungen an die Zukunft (Chariots of the Gods?) are classic examples of the genre. These works are rooted in the literary tradition of science fiction. Hubbard's text is a gnostic revelation that draws from the tradition of medical quackery and revelatory self-help books. Velikovsky's astronomical pseudo-science is based on unsupportable scenarios presented without proof. Von Daniken's archaeology of ancient astronauts reads like the headlines of current tabloids like the Weekly World News.

By no means is such pseudo-science a late twentieth-century phenomenon.[17] The creationist George McCready Price, the last and greatest of modern opponents of evolution, based his unsupportable scientific views on his devout faith in Seventh Day Adventism.

His New Geology: A textbook for colleges, normal schools, and training schools; and for the general reader (1923), is a classic in pseudo-science. According to Price, the great "sacred cow" of evolution is the belief that fossils proceed from simple to more complex forms as you move from older to younger strata. But since dating the strata is done by fossils, evolution is based on a system of circular reasoning. His alternative assertion, that creation was completed several thousand years B.C. in literally six days was in accord with his religious beliefs. William Cullen Bryan cited Price as an authority on geology during the famous Scopes trial in Tennessee. Price's book convinced an entire generation of creationists.[18]

Wilber Glenn Voliva, the leader of the Christian Apostolic Church of Zion, Illinois from 1905 to 1935 mixed his religious dogmas with his beliefs that the earth was flat, that the sun was only 32 miles in diameter, and was less than 3,000 miles away. His community of 6000 believers were exemplary in many ways: they adhered to a strict moral code and ran lucrative businesses to support their church; yet, at Voliva's insistence, their faith blended Biblical literalism with a very curious and unsupportable position on geophysics and astronomy. Voliva's desire to defend a religious dogma with pseudo-science was supported by a paranoid belief in his own greatness so far removed from reality as to border on the psychotic.[19]

Of course there are also cases of hoax (e.g. Piltdown man), health scams (elixirs or science diets, etc.) and the most ancient of pseudo-sciences, astrology.[20] These examples are by no means

exhaustive. The sincere but nonetheless deluded pseudo-scientist may have at least some of the following general characteristics:

- May range from illiterate to brilliant, but usually considers him or herself a genius.
- Believes to be unjustly ignored and/or persecuted. May be compulsive or neurotic about this. It is said that paranoia sustains the crank against all odds.
- May be well educated, but typically not in the field in which the research is done.
- Works in isolation, typically not part of a team. The crank has individualistic self-assurance, the scientist collective self-doubt.[21]
- Publishes in specialty or vanity presses, not in reviewed journals or with major publishers.
- Typically has a low regard for intelligence of others.
- Has strong compulsions to attack the greatest scientists and the best-established theories (e.g. build perpetual motion machines, develop a new theory of gravity, disprove the germ-theory of infection, etc.).
- Writes in complex, yet unconventional jargon; works are peppered with new terms, neologisms.
- Advances views contradicted by evidence, offers no reasonable grounds for serious consideration, does not participate in ongoing debate.
- May be rationalizing strongly held <u>religious or ideological convictions</u> (as in the cases of dianetics, the Christian Apostolic Church, or creationism).

That is not to say that every dubious scientific claim can immediately be dubbed as pathological science or pseudo-science. For example, one of the characteristics Langmuir listed for pathological science: "fantastic theory contrary to experience" may, in some cases, turn out to be instead: "exciting new theory invalidating previous thinking."[22] In every case, reliable and false theories about nature lie on a more-or-less continuous and relative scale. On this scale, no theories are absolute or eternal; most theories receive the grade of plausible; and all theories, according to Popper, are at least potentially falsifiable -- the demarcation of empirical science from pseudo-science being based on methodology of the practitioners.[23] In practice, both the collective judgement of the scientific community and the test of time must also be applied. Table 1 illustrates this scale for theories in astronomy, physics, and biology.

Table 1: Relative scale of scientific plausibility

Astronomy:	FALSIFIED	- Geocentrism
	PLAUSIBLE	- Expanding universe
	RELIABLE	- Special Relativity
Physics:	FALSIFIED	- N-Rays
	PLAUSIBLE	- Unified field theory
	RELIABLE	- Newton's laws
Biology:	FALSIFIED	- Lysenkoism
	PLAUSIBLE	- Darwinian evolution
	RELIABLE	- Genetic inheritance

In addition to theories, the abilities of individual researchers also lie on a continuum from the incompetent pseudo-scientist to the well-respected and competent scientific practitioner.

Socially Pathological Science

Beyond the delusions of individual researchers and their assistants or adherents, pathology may manifest itself among larger social groupings. England and America in the late nineteenth century were mesmerized by the "social Darwinism" of Herbert Spencer. Spencer applied the rules of Darwinian evolution to social evolution in support of his "law of universal social progress" -- a message the played well in the gilded age.[24] In addition to its influence on wealthy Americans such as Andrew W. Carnegie, who considered himself the fittest of the fit, Social Darwinism further influenced the eugenics movement and the development of a racially pure "Nazi science."[25] It is well-known that the overall behavior of nations may turn pathological in times of war and other social stresses, or under the influence of a dictator. So too with science. Witness the example of Stalinist Russia.

Between 1937 and 1964, Soviet genetics was dominated by the thought of T. D. Lysenko, an "illiterate and fanatical charlatan," who gained absolute dictatorial control over both research in biology and practical agriculture.[26] Lysenkoism was based on utopian assumptions about the state's power to accelerate the modernization of agriculture by altering its social organization.

The myth surrounding Lysenkoism says that it was a rejection of genetics and an acceptance of Lamarck's view that characteristics acquired by an organism can be inherited to its offspring. Such malleability of nature, especially human nature could be used to support the Marxist-Leninist theory that new conditions will create new men.[27] In reality it was much less scientific or even theoretical. Rather than an attack on science or a prop for Marxist ideology, Lysenkoism was a "self-deceiving arrogance among political bosses, a conviction that they knew better than scientists how to increase farm yields."[28] This bizarre chapter in the history of modern science stifled progress in the life sciences in the Soviet Union and, because of its negative influence on agriculture, was destructive to the Soviet economy. All the agricultural and life sciences were abused under Lysenko's irrational and brutal campaign for improved farming. It stands as an indictment of a system of centralized control of science.

Pathologies of National Science: Age and Size

In an earlier contribution to this conference titled, "Historical Perspectives on the International Transfer of Science and Technology," I presented four stages that nations typically go through as they mature scientifically. The stages were: Exploration phase, Colonial phase, Emergent phase, Scientific and Technological Maturity. Throughout history, nations reaching scientific maturity and carrying the banner of world leadership included Italy (ca. 1620), Britain (ca. 1750), France (ca. 1830), and Germany (ca. 1880). After 1930, the United States --

initially in the fields of genetics and astrophysics, and subsequently in physics, computer technology, and most other specialties -- emerged as the leading scientific nation of the world. The Soviet Union, with a distinct bias toward the applied sciences and relatively few Nobel Prize winners, has established leadership in weaponry and space technology since the 1950s.

The taxonomy I presented also included a fifth stage that may be considered the pathological stage of national scientific development: Eclipse and Decline Phase. A nation reaching the stage of scientific and/or technological maturity may or may not maintain its hard-won gains. This is certainly true for numerous ancient civilizations which had highly developed technologies, yet lost their role as world leaders and their sovereignty as well. In modern times, the nations of Western Europe are in relative decline compared to their historical "golden eras." Even the United States is now facing hard questions relating to the distribution of scarce resources for scientific research. Hard choices are also necessary due to the increasing urgency and cost of repairing and maintaining its aging, low-tech, public works, such as bridges and highways.

Another pathology affecting American science is that it has become oversized. In the decades following World War Two growth was rapid. Measured in constant (1982) dollars, funding for science from all sources rose from $19.7 billion in 1953 to $62.5 billion in 1966. During the Vietnam era it leveled off, with funding remaining about constant from 1966 to 1977. Since then funding has risen again, but at a slower rate than in the 1950s.[29] Total funding is now at about $120 billion (1987 dollars).

According to Frank Press, President of the National Academy of Sciences, the "dilemma of the golden age" of science in America lies in the fact that a golden age of discovery and scientific advance, with breakthroughs and worthy proposals in all fields, is coming at a time of record budget deficits.[30] Leon M. Lederman, President-Elect of the AAAS, paints a gloomier picture. According to him, science in America may be reaching "the end of the [endless] frontier."[31] With level federal funding, a growing scientific community, increased costs of doing research, and non-defense R & D as a percentage of gross domestic product lagging far behind that of Japan and Germany, moral of U.S. scientists is low. The report concludes that, "American science shows signs of extreme stress."[32] The health of the scientific enterprise in America is at risk. The question remains -- if you agree with the premise of the report -- was this potentially pathological situation caused by the bloated, overindulgent scientific lifestyle of American research and development?

Conclusion

Pathological science comes in many forms. For individuals working at the limits of their instruments, it may begin as a spurious result, mistake, or delusion, that, if pursued, may take on a life of its own with serious consequences for the researcher: public embarrassment, the end of a career, or even suicide. Close associates in a research group may also experience a group delusion if pet theories are not put to rigorous independent

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tests. The social context in which science is done also undoubtedly contributes to the emergence of pathological science. Priority disputes, career and funding pressures, and even the current crisis in the peer review process can push a researcher to premature publication or allow a substandard piece of work to get through. As the case of Irving Langmuir's enthusiasm for weather modification shows, not even Nobel Prize winners, especially if they invade the professional territory of other scientists, are immune to pathological behavior.

Other manifestations of pseudo-science, particularly cases of hoax and outright fraud are more like diseases that attack the scientific community where it is most vulnerable -- in the realm of public perception of science. The case of Iben Browning a self-taught seismologist who based his predictions of a major earthquake in New Madrid. Missouri for December 3rd, 1990 on planetary and lunar alignments is perhaps typical. There was widespread public awareness of the prediction, especially in New Madrid, a city that has remained basically quakeless for about two centuries. Schools and businesses were closed that day; emergency relief teams were on full alert status; the media had a field day covering the event; songs, tee-shirts and paraphernalia were produced commemorating the upcoming quake; many people chose to leave town. Because of the publicity, a small number of people became aware of the fact that the sun and the moon (but not the planets) produce tidal effects on land similar to those produced in the oceans. This has been known by geophysicists for many years. Almost no one, however, bothered to note that the stresses

associated with these tidal forces are not correlated with times of seismic activity.[33] So Mr. Browning playing the role of a pseudo-scientist, appeared as a prophet of impending doom to announce the very day of destruction -- well, perhaps next time.

Pathology also may infect a national scientific establishment, as it did in Nazi Germany or Stalinist Russia. Even in the best of situations, we have seen that scientific prowess does not linger long with any one nation, as was the case with Italy where much of the scientific revolution got its start. Science in the United States of America is currently showing signs of potentially pathological stress related to its extremely large size and the impossibility of sustaining decade after decade of net growth.

These pathologies of science, whether caused by epistemological limits, moral turpitude, social pressures, or economic realities are all part and parcel of the ongoing business of science. Not only is nature reluctant to reveal its secrets without a tremendous effort by investigators, but human nature and the social structure conspire to make it more difficult as well.

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Endnotes

[1] Trevor I. Williams, Science: A History of Discovery in the Twentieth Century (New York: Oxford University Press, 1990), 68. As examples of error, deception and fraud, Williams cites the case of the midwife toad and Lysenkoism. He briefly alludes to the Piltdown forgery, the fossil Archaeopteryx, and cold fusion.

[2] The Irving Langmuir Papers in the Manuscript Division of the Library of Congress contain the original lecture note cards, "Pathological Science," dated Dec. 18, 1953, as well as a sound recording and transcript of the seminar. A recent version, Irving Langmuir, "Pathological Science," transcribed and edited by Robert N. Hall appeared in Physics Today (Oct. 1989): 36-48. For more on Langmuir see Albert Rosenfeld, The Quintessence of Irving Langmuir, vol. 12 of The Collected Works of Irving Langmuir (Oxford, Pergamon Press, 1966).

[3] I embellished Langmuir's list, originally written on a note card, with the help of Peter W. Huber, "Pathological Science in Court," Daedalus (Fall 1990), 97-118.

[4] This account of N-Rays follows that of Derek J. de Solla Price, Science Since Babylon (New Haven, 1975), 153-59. See also Jean Rostand, Error and Deception in Science: Essays on Biological Aspects of Life. Transl. from the French by A.J. Pomerans (New York: Basic Books, 1960). Wood published the letter debunking N-rays in Nature 70 (1904): 530.

[5] Spencer Weart, "A Little More Light on N-Rays." American Journal of Physics 46 (1978): 306.

[6] "Cold Fusion: Only the Grin Remains," Science 250 (1990): 754; Huber, "Pathological Science in Court."

[7] This section is based on James R. Fleming, "Cloud Wars: Weather Modification and the Military, 1947-1977," in Nathan Reingold and David Van Keuren (eds.) Science and the Federal Patron: Post-World War II Government Support of American Science (Chicago: University of Chicago Press, in press). See also the very perceptive letter by Robert G. Fleagle in "Second Opinions on 'Pathological Science'," Physics Today (March 1990): 110.

[8] Vincent Schaefer, "The Production of Ice Crystals in a Cloud of Supercooled Water Droplets," Science 104 (1946): 459. See Horace

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Byers, "History of Weather Modification," in Wilmot N. Hess (ed.), Weather and Climate Modification (New York, 1974), 9.

9 "Project Cirrus — The Story of Cloud Seeding," G.E. Review (November 1952), 12.

10 During World War II the National Defense Research Council, the Office of Scientific Research and Development, the Chemical Warfare Service, the Secretary of War, and the Army Air Forces sponsored research on gas mask filters, screening smokes, precipitation static, and aircraft icing studies. Langmuir and Shaefer had been involved in this work. See Irving Langmuir, "The Growth of Particles in Smokes and Clouds and the Production of Snow from Supercooled Clouds," Proceedings of the American Philosophical Society 92 (1948): 167.

11 Irving Langmuir, "Summary of Results Thus Far Obtained in Artificial Nucleation of Clouds," in Final Report: Project Cirrus, G.E. Report No. RL-140 (Schenectady, N.Y., 1948), 18.

12 James R. Fleming, "Irving Langmuir's Weather Modification Experiments for General Electric and Project Cirrus: A Case Study of the Limits of Private Support for Science," paper presented at the annual meeting of the American Meteorological Society, 1984.

13 Manuscript note card, "TV Aug. 24 8:33 AM," Irving Langmuir Papers, Manuscript Division, Library of Congress, Washington, D.C.

14 Irving Langmuir, "The Production of Rain by a Chain Reaction in Cumulus Clouds at Temperatures Above Freezing," Journal of Meteorology 5, no. 5 (1948): 110ff. This theory considers the development of precipitation in warm clouds by the collision-coalescence of drops that grow so large they break up into smaller drops and are carried upward to repeat the cycle, forming a so-called chain reaction. Although accounts of these developments exist in the scientific and journalistic literature, until now they have not attracted the attention of professional historians of science and technology. See for example Byers, "History of Weather Modification," 3-24; and Barrington S. Havens (compl.), "History of Project Cirrus," General Electric Research Laboratory Report No. RL-756 (Schenectady, N.Y., 1952). Archival materials are found in the Irving Langmuir Papers in the Library of Congress, and in the archives of the General Electric Company.

15 "Rain Making Ineffective," Science News Letter (December 11, 1948): 375. Robert G. Fleagle, "Background and Present Status of Weather Modification," in Fleagle (ed.), Weather Modification: Science and Public Policy (Seattle, WA: Univ. of Washington Press, 1968), 9-10. Weather Bureau Chief F. W. Reichelderfer claimed that the press had cast his agency in the role of the conservative

and reactionary villain; see letter from F.W. Reichelderfer to Fortune 38 (March 1948): 38.

16 A very popular and influential book on the subject of pseudo-science is Martin Gardner, In the Name of Science: Fads and Fallacies in the Name of Science (New York, 1952). More recent books include Marsha P. Hanen, Margaret J. Osler, and Robert G. Weyant (eds.), Science, Pseudo-science, and Society, published for the Calgary Institute for the Humanities (Waterloo, Ont.: Wilfrid Laurier University Press, 1980); and Max. J. Charlesworth, Science, Non-science & Pseudo-science: Bacon, Popper, Lakatos, Kuhn, and Feyerabend on Defining Science (Victoria: Deakin University Press, 1982).

17 See, e.g. Arthur Wrobel (ed.), Pseudo-science and Society in Nineteenth-century America (Lexington, Ky.: University Press of Kentucky, 1987).

18 A full and authoritative account of creationism is found in Philip Kitcher, Abusing Science: The Case Against Creationism (Cambridge, Mass.: MIT Press, 1982). See also Ronald L. Numbers, "Creationism in 20th-Century America," Science 218 (1982): 538-44; and Ronald L. Numbers, "The Creationists," in D. C. Lindberg and R. L. Numbers (eds.), God and Nature: Historical Essays on the Encounter between Christianity and Science (1986), 391-423.

19 Ibid., 16-19.

20 On Piltdown see Frank Spencer, Piltdown: A Scientific Forgery (London: Oxford University Press, 1990); and Frank Spencer, The Piltdown Papers, 1908-1955: The Correspondence and Other Documents Relating to the Piltdown Forgery (London: Oxford University Press, 1990). On medical quackery see James Harvey Young, The Medical Messiahs: A Social History of Health Quackery in Twentieth-century America (Princeton, N.J.: Princeton University Press, 1967). On astrology, see any number of books, e.g. Bart J. Bok and Lawrence E. Jerome, Objections to Astrology (Buffalo, N.Y.: Prometheus Books, 1975).

21 David Joravsky, The Lysenko Affair (Chicago, 1986),39.

22 Letter from Christopher Cooper, "Second Opinions on 'Pathological Science'," Physics Today (March 1990): 13-14.

23 Karl Popper, Logik der Forschung (1934); and Popper, Conjectures and Refutations (1963).

24 Richard Hofstadter, Social Darwinism in American Thought (Boston, 1955).

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[25] Daniel Kevles, In the Name of Eugenics: Genetics and the Uses of Human Heredity (New York: Knopf, 1985); Daniel Gasman, The Scientific Origins of National Socialism: Social Darwinism in Ernst Haeckel and the German Monist League (London: Macdonald & Co., 1971); and Joseph Needham, The Nazi Attack on International Science (London: Watts & Co., 1941).

[26] Zhores A. Medvedev, The Rise and Fall of T. D. Lysenko, transl. I.M. Lerner (New York, 1969), v.

[27] The neo-Larmarckian biologist Paul Krammerer, who took his life during the case of the mid-wife toad fraud in Vienna, had been invited to set up a research institute in the Soviet Union. After his death he became a popular hero there, primarily because of the Russian movie about his life titled Salamandra. See Arthur Koestler, The Case of the Midwife Toad (New York: Random House, 1971), 13-15.

[28] Joravsky, Lysenko Affair,vii.

[29] Figures were taken from Bruce L. R. Smith, American Science Policy Since World War II (Washington, D.C.: Brookings Institution, 1990).

[30] Frank Press, "The Dilemma of the Golden Age," annual address of the President of the National Academy of Sciences (Washington, D.C., 1989). Of course the "endless frontier" is a reference to United States Office of Scientific Research and Development, Science, The Endless Frontier,. A report to the President by Vannevar Bush, July 1945 (Washington, D.C., GPO, 1945).

[31] Leon M. Lederman, "Science: The End of the Frontier?" Supplement to Science (January 1991).

[32] Ibid., 17.

[33] Thomas Heaton, "Tidal Triggering of Earthquakes," Bulletin of the Seismological Society of America 72 (1982): 2181-2200.