Book Review

The End of Science: Facing the Limits of Knowledge in the Twilight of the Scientific Age

Reviewed by David Hoffman

The End of Science: Facing the Limits of Knowledge in the Twilight of the Scientific Age
John Horgan
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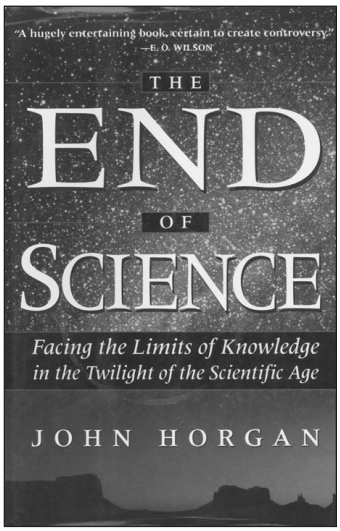
Four years ago John Horgan, then a senior staff writer for *Scientific American,* published in that journal "The Death of Proof", a piece that claimed that "video proofs" were transforming mathematics. Among other things,"The Death of Proof" suggested that Wiles's announced resolution of Fermat's Last Theorem might be a "splendid anachronism", one of the last great formal proofs. As it turns out, Horgan's ten-page mathematics-as-we-knew-it-is-over article was merely a finger exercise for a full-scale requiem for science—the book under review here.

The bulk of *The End of Science* consists of a series of interviews, some originally done for *Scientific American*, linked together by the thesis that science as we know it is coming to an end because it is close to achieving its goal, explaining nature. Horgan credits his agent for turning an amorphous idea into a marketable proposal. The agent is pretty good. The book has been widely publicized, and Horgan has appeared on the high-toned TV and radio talk shows. Short pieces based on *The End of Science* have appeared in magazines and newspapers, including the *New York Times* and the *International Herald Tribune.*



Horgan writes in a sly and entertaining manner, often taking the imagined reader's side against scientists whom he portrays as blinded by their own success and ambition. There is little serious explanation of scientific ideas in the book. Nonetheless, it must be taken seriously. Writers like Horgan and books like *The End of Science* influence the public image of science.

I should say here that I was interviewed for Horgan's "Death of Proof" article and felt misled by him. Because of this I was not favorably disposed toward this book before I read it. I liked it less afterward. But more disturbing to me is the fact that a former colleague who read an article by Horgan—extracted from *The End of Science* and published in *Technology Review*—thought it profound. I think it is profoundly wrong. My main focus in this review will be on the aspects of *The End of Science* that I found most troubling: a clear antipathy toward mathematical thinking and a fundamental misunderstanding of the uses of mathematics in science. Books like this cloud the

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public understanding of what we do, to our detriment.

Is Science PM?

To support his thesis that science is reaching its limit, Horgan concocts the notion of "ironic science", which he has explained in the following way.

> Some of the most prominent scientists in the world traffic in hypotheses that are remarkably postmodern in character. I like to call this type of theorizing ironic science. The concept of irony is central to that wellspring of postmodernism, literary criticism.…The job of a literary critic is.…not to pin down the true meaning of the text—an impossible task—but to invent new meanings, ones that challenge received wisdom and provoke further dialogue. Similarly, ironic science advances hypotheses that, while often profound, should not be considered literally true. My favorite example of ironic science is superstring theory.…[1]

So-called ironic science is blooming, according to Horgan, because the job of science is largely done. Its theories (quantum mechanics and general relativity, molecular biology and evolution) give a framework that will last for thousands of years. They explain the explainable, Horgan tells us. To him they are true. We are approaching the limits of knowledge; further theorizing will only lead to speculation that cannot be verified or falsified by experiment. While sometimes beautiful, such intellectual activity has more in common with *The Inferno* of Dante than with the *De Revolutionibus* of Copernicus. Strong scientists, those not content with working out the mere consequences of the now-and-future canon, must become practitioners of ironic science. Or do something else.

I have a problem with the word *invent* as it is used here. Horgan not only misrepresents the scientific enterprise, he also does a disservice to serious literary theorists by confusing fabrication with invention. Surely serious critics of any school do not make up meanings; they seek them in the text and in the way the text is used in social interaction. That is, they *invent* them in the classical sense of the word; they do not fabricate them as Horgan implies.

Horgan is confused not only about what he believes scientists are doing but, as a self-styled postmodern critic of science, about what he himself is doing. Can it be that a critic of any sort would draw conclusions without reading the text, no matter what else is considered important? Horgan draws sweeping conclusions about scientific theory that he does not pretend to understand by merely interviewing scientists. When he does not like their answers, he refutes them with derisive personal comments, the gist of which is that scientists, like authors, are not to be trusted when explaining their own work.

Horgan's main argument to support the contention that current scientific theories are the final theories goes something like: Because they are true. Horgan presents other lines of reasoning that contradict one another. On the one hand, the lack of fundamental advances in some scientific areas is taken as evidence that these fields are close to their intellectual conclusion. On the other, the proliferation of theoretical advances in some areas of science in the last two decades is not an indication that these sciences are thriving. Rather, Horgan interprets this as evidence that these disciplines are rapidly completing their tasks in a flurry of activity that marks the end of their life cycle; they are approaching the "limits of knowledge in the twilight of the scientific age." Science cannot continue past this limit. He wants to have it both ways.

These dubious arguments are topped by what Horgan calls "the sun principle". For example, generalizing from the statement that "No one really knows what causes sunspots," Horgan concocts this extrapolation: "Our ability to describe the universe with simple, elegant models stems in large part from our lack of data, our ignorance. The more clearly we can see the universe in all its glorious detail, the more difficult it will be for us to explain with a simple theory how it came to be that way." I find this simplistic and wrong. For me, the recent visual constructions made from Hubble-telescope data evoke a sense of wonder and the faith that the eventual understanding of what these images mean will fundamentally alter our view of the history of the cosmos. Horgan ignores the complex interaction among theory, experiment, and instrument building which characterizes modern science, in particular the regularity with which acquisition of fundamentally new data challenges the very theory that initiated the search for it.

Body Blows

But Horgan has other, indirect ways to build up his case; he substitutes personalities and gossip for ideas and analysis. The thesis of the book requires the assumption that "Science" is a well-defined, generally understood entity. To explain in any detail even one scientific theory, let alone argue that all theories are part of a single endeavor, is beyond the scope of Horgan's book. Horgan solves this problem by replacing "Science" by "scientists". Many of the scientists in the book, especially ones that Horgan does not like, are presented as weird

[1] *Quoted from* Postmodern irony may be profound, but it's strange science, *International Herald Tribune, July 17, 1996.*

people, put out that their privileged place in the world is being challenged. Their understandable annoyance with Horgan is reported as defensiveness and interpreted as arrogance. Horgan loves to play the role of the exposer, the clear-seeing child in his private version of *The Emperor's New Clothes.* But he is no innocent. The book is filled with mean-spirited remarks about clothing, grooming, skin texture, thick accents, and other personal characteristics. Condescending and occasionally crossing the border into downright nastiness, these asides set the tone of the book.

Here are a few examples.

- About the evolutionary biologist Richard Dawkins:

  > He is an icily handsome man, with predatory eyes, a knife-thin nose, and incongruously rosy cheeks. He wore what appeared to be an expensive, custom-made suit. When he held out his finely veined hands to make a point, they quivered slightly. It was the tremor not of a nervous man, but of a finely tuned high-performance competitor in the war of ideas: Darwin's greyhound.

  This is mild; Horgan actually admires Dawkins.
- About the mathematician Mitchell Feigenbaum:

  > When amused, Feigenbaum did not smile so much as grimace.…his already protuberant eyes bulged still farther from their sockets, and his lips peeled back to expose twin rows of brown, piglike teeth stained by countless cigarettes and espressos (both of which he consumed during our meeting). His vocal cords, cured by decades of exposure to these toxins, yielded a voice as rich and resonant as a basso profundo's and a deep, villainous snicker.

- About the physicist Andrei Linde:

  > For someone so publicly playful and inventive, Linde can be surprisingly dour.…When I arrived at the gray, cubist house they were renting, Linde gave me a perfunctory tour. In the backyard, we encountered Kallosh, who was rooting happily in a flower bed. 'Look, Andrei,' she cried, pointing to a nest filled with cheeping birds on a tree branch above her. Linde, his pallor and squint betraying his unfamiliarity with sunlight, merely nodded. When I asked if he found California relaxing, he muttered, 'Maybe too relaxing.' As Linde recounted his life story, it became apparent that anxiety, even depression, had played a significant role in motivating him.

- About the physicist David Bohm:

  > His skin was alarmingly pale, especially in contrast to his purplish lips and dark wiry hair. His frame, sinking into a large armchair, seemed limp and languorous, but at the same time suffused with nervous energy. He cupped one hand over the top of his head; the other rested on the armrest. His fingers, long and blue veined, with tapered yellow nails, were splayed. He was recovering, he told me, from a recent heart attack.

The tone of these remarks serves a thematic purpose, namely, to convey the sense that the heroic age of science is over, its great lights dead or dying. What few new heroes there are do not belong in the same class as their predecessors. George Andrews has called Horgan the self-styled "Jack Kevorkian of Science". To me, this refers to more than the Horganian theme of the twilight of the scientific age. I do not mean to challenge the view of Kevorkian as a humanitarian who, by facilitating the suicide of those with painful and terminal illness, eases their transition to finality. Rather, I want to call attention to the recurring motif of morbidity in Horgan's interviews. The bodies of scientists are offered up in place of a body of scientific knowledge. Age and decay become evidence for the theme that we are entering the twilight of the scientific age.

Given the people Horgan interviews, it should be expected that some of them would express regret, even sadness, at coming to the end of a career without having understood, to their satisfaction, important aspects of the scientific problem that motivated them in their youth. Disappointment expressed by scientists at their own human limitations—that the problem was more difficult than expected or that they will not live to see a complete resolution—is interpreted as a comment on the limits of science itself. Missing an opportunity to explore and present in a sympathetic manner human stories of how personality, theory, and career interact in the course of the lives of some very interesting people, Horgan misrepresents these personal remarks as statements about the state of science itself. Worse, in some of the interviews, scientists are engaged in conversations that evidently have nothing to do with the notion of the "end of science". Horgan writes it up in a way that makes his case; the scientists have no opportunity to respond to the picture Horgan is painting.

The Death of Proof

This questionable journalistic technique was already in use in the preparation of the "Death of

Proof" article. When I was interviewed for that one, Horgan did not mention that the article was to be about the demise of traditional proofs and the rise of "video proofs". Rather, I was led to believe that it was a survey of the various uses of computers in mathematics. About six weeks before the article was published, Horgan phoned me, ostensibly to clarify some technical matter in his article. He soon changed the topic of conversation, asking me what I thought about the notion of a "video proof". At first I had no idea what he was talking about. He said he was referring to the notion that animations were replacing traditional proofs in avant-garde mathematics. I asked him where he had gotten such an idea. He would not say. I asked if this had anything to do with the article, and he changed the subject. Only when the "The Death of Proof" appeared in print did I have a clear idea of what the article was about.

Some of the mathematicians discussed in the article claimed that they were quoted out of context, and many letters of protest were written. The article angered me, and in October 1993 I wrote a letter to the editor of *Scientific American*, which began

> "The Death of Proof" by John Horgan defies logic and accuracy in favor of controversy and sensationalism. The juxtaposition of Wiles' announced proof of Fermat's Last Theorem (wrongly referred to as an "anachronism") with the video *Not Knot*, made to explain and illustrate ideas in geometry (incomprehensibly called "a video proof") is silly. However, when the two are interpreted as landmarks in the downfall of rigorous mathematics, it is idiotic. I am very much in favor of the use of computer graphics in mathematical research and communication, but is there one respectable mathematician willing to explain and defend the notion of video proofs as a replacement for traditional mathematical methods?

Horgan was stung by the torrent of howls and complaints he received from mathematicians. We were the group of scientists, he said, who whined most about not getting enough press coverage. But when we got it, we complained that it was wrong or inaccurate. He expressed particular disappointment with me personally. I had let him down. He thought I was "with it". When I asked "With what?" he did not answer. I guess now I know what he meant.

What Really Gets Horgan's Goat

Horgan's favorite example of ironic science is superstring theory, which in his mind

> … for the last 15 years has represented the cutting edge of physics. Sometimes called a "theory of everything," it posits that all the matter and energy in the universe, and even space and time, stem from infinitesimal loops of ur-stuff writhing in a hyperspace of 10 (or more) dimensions.

For Horgan the absurdly high-dimensional space in which superstrings live is only slightly less ridiculous than their small size: "The tiny domain that superstrings supposedly inhabit is even less accessible than the quasars haunting the edge of the universe. A superstring is to a proton in size as a proton is to the solar system."[2]

Edward Witten is Horgan's "leading practitioner" of string theory, "the most spectacular practitioner of naive ironic science" that Horgan has ever encountered. According to Horgan, Witten "believes in his speculations, even though they have not been empirically verified," and he is like other naive scientists who "believe they do not invent their theories so much as they discover them…." Witten"—like a Texan who thinks that everyone but Texans has an accent—does not acknowledge that he or she [a scientist] has taken any philosophical stance at all." Horgan thinks that Witten is the sort of scientist who believes that he is "just a conduit through which truths pass from Platonic realm to the world."

What does this have to do with the content of string theory? Nothing. A clue to why Horgan may think it is relevant can be found in the article, based on *The End of Science*, which appeared in the *International Herald Tribune*.[3] In it Horgan mentions the paper by the physicist Alan Sokal which was published in the journal *Social Text*. Sokal held up superstring theory as a breakthrough, one that would free science from its dependence on the fictional notion of objectivity. After its publication Sokal announced that his paper was in fact a parody of current so-called postmodern writing about science. But according to Horgan: "superstring theory is exactly the kind of science that subverts conventional notions of truth…it is highly unlikely that we will know whether superstring theory is true. That is what makes it ironic."[4]

In fact, in Horgan's view of things it is mathematics that "subverts conventional notions of truth." When Witten, apparently none too happy about having agreed to be interviewed by Horgan, suggests that he should write profiles (presumably for *Scientific American*) of five mathematicians, Horgan's response is not to Witten but to us: "Wit-

[2] *International Herald Tribune,* Postmodern irony, *July 17, 1996.*

[3] *Ibid.*

[4] *Ibid.*

ten did not realize that he was providing fodder for those who claimed he was less a physicist than a mathematician." When one of Witten's colleagues described him to Horgan as "possessing the greatest mathematical mind since Newton," it is miscast by Horgan to mean that Witten is a mathematician and therefore not a real physicist. Continuing with this theme, Horgan writes: "In the late 1980s Witten created a technique—which borrowed from both topology and quantum field theory—that allows mathematicians to uncover deep symmetries.... As a result of his finding, Witten won the 1990 Fields Medal, the most prestigious prize in *mathematics*" (emphasis in the original). The italics emphasize that Witten's work is mathematics, i.e., not really physics, not really science at all.

Witten tells Horgan that the development of the sort of mathematics that will allow increased understanding of string theory will also lead to the construction of experiments to test and refine it. Horgan does not appear to understand what Witten is trying to say, and Witten's exasperation with Horgan is evident: "I don't think I've succeeded in conveying to you its (string theory's) wonder, its incredible consistency, remarkable elegance, and beauty." This is interpreted by Horgan as a claim that "superstring theory is too beautiful to be wrong." "I asked Witten how he responded to claims of his critics that superstring theory is not really physics at all," Horgan continues. "Witten replied that it predicted gravity." Since, to Horgan, gravity needs no prediction—it has been discovered and verified, so it is true—this response is taken by Horgan as further indication of the occult nature of string theory. Horgan certainly knows better, but he refuses to relent on this point.

The high dimension and the small scale of superstring theory make it a priori ironic to Horgan. In his mind it has no connection with reality—it is unable to serve any real purpose in a true, non-ironic scientific endeavor. It is not testable and does not further our understanding of what the world and the universe are really like. Horgan misses the point that the theory is not one of an infinite number of theoretical explanations, that there is nothing arbitrary about its formulation. Is it less problematic to assume that every physical system is associated to an infinite-dimensional, normed vector space whose unit-length vectors represent its states? Of course, the difference is that quantum mechanics provides a theory that is testable on a small scale and can give numerical predictions in agreement with the most delicate experiments. While no significant experiments have been done to test string theory, this does not mean that no such experiment is possible, as Horgan assumes. In fact, there are plans to attempt to detect supersymmetry at the Large Hadron Collider at CERN, a facility that is expected to be operational in a decade. Supersymmetry, a symmetry between bosons and fermions, is one of the main predictions of string theory. I do not know if the plans for this experiment were known to Horgan at the time of his interview of Witten or at the time of publication of *The End of Science*.

Horgan furthers his case that superstring theory has little connection with reality by trying to portray Witten in the same vein. First he sets up Witten as "the smartest physicist of them all," the Albert Einstein of the end of the twentieth century, and he makes it quite clear that he is interviewing Witten at the Institute for Advanced Study. But instead of a shaggy-haired icon with a charming accent and a violin, rivaling Charlie Chaplin in popularity, we have presented to us by Horgan a mean-spirited caricature of a man: one who talks in a "highly abstract, impersonal mode of speech"; who "paused frequently—for 51 seconds at one point—casting his eyes down and squeezing his lips together like a bashful teenager"; and who "now and then—for no reason I could discern—broke into convulsive, hiccupping laughter as some private joke flitted through his consciousness." This portrayal is meant to convey, by association, a fundamental difference between general relativity and superstring theory. On one part of Long Island, where I grew up in the fifties, it was believed that only four people in the world understood relativity theory—one for each dimension of space-time, I suppose—but this did not make it suspect, rather the opposite. Science extended reality and instilled wonder, not ridicule. Horgan's caricature of superstring theory casts it as a fabrication devoid of meaning. That it seems to predict gravity, as Witten tries to emphasize, makes no sense at all to Horgan—gravity is already explained. Witten has already slipped up and admitted that he is a mathematician, that he is not dealing with reality at all, just speculation and austere abstraction whose meaning has nothing to do with physics and can never be verified or disproved.

Revolution

> Meeting a friend in a corridor, Wittgenstein said: "Tell me, why do people always say that it was *natural* for men to assume that the sun went around the earth rather than that the earth was rotating?" His friend said, "Well, obviously, because it just *looks* as if the sun is going around the earth." To which the philosopher replied, "Well, what would it have looked like if it had looked as if the earth was rotating?"
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> —*from* Jumpers[5]*, a play by Tom Stoppard.*

[5] *Grove Press, Evergreen Edition, New York, 1974, p. 75.*

Horgan's objections to string theory and to Witten are based on a fundamental misunderstanding of the relationship between mathematics and physical theory. "Let's give superstring believers the benefit of the doubt, if only for a moment," he says.

> Let's assume that some future Witten, or even Witten himself, finds an infinitely pliable geometry that accurately describes the behavior of all known forces and particles. In what sense will such a theory explain the world? I have talked to many physicists about superstrings, and none has been able to help me understand what, exactly, a superstring *is*: it is some kind of mathematical ur-stuff that generates matter and energy and space and time but does not itself correspond to anything in our world….The true meaning of superstring theory, of course, is embedded in the theory's austere mathematics. I once heard a professor of literature liken James Joyce's gobbledygookian tome *Finnegan's Wake* to the gargoyles atop the Cathedral of Notre Dame, built solely for God's amusement. I suspect that if Witten ever finds the theory he so desires, only he—and God—will appreciate its beauty.

Let's leave aside the fact that Horgan has to drag in James Joyce, the Cathedral of Notre Dame, and some unnamed—probably misquoted—teacher of his in order to give a scholarly patina to his snide equating of string theory with gobblydegook. Let's ignore his short count of people able to appreciate string theory: one—or two, if you count God—down from the fabled four who understood general relativity according to fifties' lore on Long Island. The real problem is not this nonsense. It is something more fundamental. The Nobel Prize-winning chemist Hans Krebs once wrote that "Those ignorant of the historical development of science are not likely ever to understand fully the nature of science and scientific research."[6] Horgan has no comprehension of the way in which a new and radical theory—at first defying common sense, and often mathematical—can become accepted as physical reality, usually after a period of rejection and incredulity. There are many examples of this phenomenon in the history of science, and I will briefly discuss two of them.

The most famous example is Newton's postulation of gravity without any attempt to describe a means for its transmission. This was considered by many of Newton's contemporaries, Leibniz included, as unacceptable. The attribution of "occult qualities" to matter was considered a serious mistake that threatened to destroy faith in not only natural philosophy, which seeks reasons, but also in divine wisdom, which provides them.[7]

The second example, and in my opinion the clearest one, was the slow acceptance of the motion of the earth. Published in 1543, the *De Revolutionibus* of Copernicus was accepted as the greatest astronomical work since Ptolemy. But according to Thomas Kuhn, "the success of the *De Revolutionibus* does not imply the success of its central thesis, namely that the earth was rotating and moving around the sun. The faith of most astronomers in the earth's stability was at first unshaken. Authors who applauded Copernicus' erudition, borrowed his diagrams, or quoted his determination of the distance from the earth to the moon, usually either ignored the earth's motion or dismissed it as absurd."[8] This was the case even though there were some astronomical computations that were improvements over values derived from Ptolemaic principles.[9]

The motion of the earth was not accepted until well into the seventeenth century. Apart from the religious and scriptural objections, "the debate about the earth's motion became bitter and intense. The earth's motion, it was said, violated the first dictate of common sense; it conflicts with long-established laws of motion."[10] It was generally felt that the desire to make the motion of the stars seem simpler was insignificant reason for positing the rotation of the earth and its revolution around the sun. It was considered a convenient geometric device, with no substantive basis in

[6] *Hans A. Krebs,* The history of the tricarboxylic acid cycle, *Perspectives in Biology and Medicine vol. 14, 1970, pp. 154–170.*

[7] *For a fascinating discussion of conflicting views on the meaning of gravity among Newton's contemporaries, see* Newtonian Studies, *Alexandre Koyré, Harvard University Press, Cambridge MA, 1965: in particular, Appendix B to Chapter III.*

[8] *Thomas Kuhn,* The Copernican Revolution: Planetary Astronomy in the Development of Western Thought, *Random House, New York, 1957. Kuhn is skewered by Horgan in his discussion of his more famous book,* The Structure of Scientific Revolutions. *Horgan tells us that "according to literary theory, Kuhn himself cannot be trusted to provide a definitive account of his own work." Horgan, of course, can. Shortly before his death, Kuhn remarked that he had more in common with those who strongly disagreed with* The Structure of Scientific Revolutions *than with those who believed with Horgan that it was a "seminal postmodern text".*

[9] *But things were not all that simple. There was not an across-the-board improvement, and some of the predictions derived using the Copernican "fiction" that the earth was in motion around a fixed sun were somewhat less accurate than those derived from Ptolemaic theory. The computations, however, were easier.*

[10] *Kuhn, op. cit.*

physical reality. After a long time—and after Kepler and Galileo—it finally became accepted that the solid earth could move around the sun in reality, not just in mathematics. And it is worth noting that the acceptance of the motion of the earth required really serious mathematical work, both pure and applied.

A great triumph of Newton's *Mathematical Principles of Natural Philosophy* (the *Principia*), published in 1686, was the derivation of Kepler's Laws, by means of the newly developed calculus, from the assumption of the inverse-square law for gravitational attraction. So the motion of the earth and planets comes to be explained by a force that can also be used to explain why ripe apples fall to the ground. But what explains or predicts gravity? How can masses act on each other at a distance (through what medium?), and how can they influence each other in a manner that appears to be instantaneous? These are good questions that could not be answered in the eighteenth century. Newton's "system of the world" was accepted without answers to these questions. But the questions did not go away; they are fundamental questions.

The End

Near the beginning of *The End* Horgan anticipated the fact that he would be branded as pathetically shortsighted. In order to deflect this criticism he retells the well-known story of a nineteenth-century commissioner of patents who suggested that the patent office should be closed because there would soon be nothing left to invent. This story is apocryphal, Horgan claims, and has very little basis in historical reality. Fair enough. But just wait a hundred years or so. People who write about, think about, and do science and mathematics at the end of the twenty-first century will not have to dredge up half-true stories of patent commissioners to point out the shortsightedness of their post-postmodern critics. They will have Horgan's *End* to kick around.