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Book Reviews

John Horgan, *The End of Science* (Reading, MA: Addison-Wesley, 1996), x + 308 pp., $24.00.

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Mr. Horgan's indictment is amplified a trifle in the subtitle on the jacket: *Facing the Limits of Knowledge in the Twilight of the Scientific Age.* Support for the charge that "pure science might be over" provides both the generating force and leitmotiv for his book. He charges that there is little more of a fundamental character that could be expected to be discovered. This charge is an armature on which a substantial intellectual structure is sculpted. The method employed is the interview with leading practitioners in fields indicated by the chapter headings. These interviews are not presented in bare Q and A form, but are a skillful weaving of paraphrased questions and answers, exact quotations, and comments into a seamless exposition of the concepts involved and judgements made.

Mr. Horgan is a competent, well-qualified prosecutor. He has for many years been a staff writer for *Scientific American,* in which capacity he has not only honed his journalistic skills but has had the opportunity to interview many of the leading scientists of our time. They range from Roger Penrose to Thomas Kuhn, from Steven Weinberg to Stephen Jay Gould to Noam Chomsky. He is very familiar with the scientific evidence. But, does he prove his case? In Scotland, in distinction to other Anglo-Saxon jurisdictions, there are three possible verdicts in a criminal proceeding: Not Guilty, Guilty, and Not Proven. The latter is not equivalent to our Mistrial. It means just what it says, i.e., Not Proven. Everything is left hanging. Mr. Horgan's indictment must be judged Not Proven.

In the prosecution of the case there is a great deal of ground to be covered. Not since the mid-nineteenth century has it been possible for a scientist to know all of science, i.e., to be able to work creatively in any and all fields. At the present time it is not even possible, in this sense, for a physicist to know all of physics. Indeed, the *Physics and Astronomy Classification Scheme* (American Institute of Physics, 1992) runs from "00. General" to "90. Geophysics, Astronomy, and Astrophysics" and takes more than 26 pages to list the complete taxonomy. Were such a classification constructed for all of the physical, life, and social sciences it might well be the size of the Manhattan White Pages.

Clearly, Mr. Horgan must constrain his choice of topics. This he does by restricting the discussion to an interesting array of disciplines: Philosophy of Science, Physics, Cosmology, Evolutionary Biology, Social Science, Neuroscience, and Chaos and Complexity, which Horgan combines into Chaoplexity. In addition, there are final chapters entitled "The End of Limitology" and "Scientific Theology, or The End of Machine Science" and an "Epilogue: The Terror of God." These latter resemble in structure the earlier chapters, but they are largely speculative.

One might ask some questions about the choices. If evolutionary biology is coming to an end, do paleontology and geology have an infinite future? Why is philosophy of science included? This discipline does discuss many fascinating issues. The argument over Karl Popper's concept of "falsifiability" is entertaining, but is it anything more? It does not seem to have the slightest relevance to the *practice* of science. These questions and others concerning your favorite science must be put to Mr. Horgan. Perhaps he intends his selections to be exemplars and the pessimistic conclusions are to be extrapolated to all of science.

Mr. Horgan's definition of science is broad enough to include almost any activity that a reasonable person might call scientific. (In this context we do not consider "reasonable" believers in astrology, a flat earth, or channeling.) His choice of topics is, of course, not so broad. It is possibly limited by the number of people he might have been able to interview, the preparatory reading he had time to absorb, and the disciplines chosen to support his thesis. The result is the eclectic mix noted earlier.

In various fields he attempts to buttress his view that science is coming to an end because what can be accomplished has now very nearly been accomplished. For various disparate reasons little more can be added. In a number of instances he cites increasing public apathy to science and a drying up of financial support. There is also a burgeoning Luddite public antipathy to science as a source of much that is evil. This is scarcely to be taken seriously. Both are entirely beside the point. One recalls readily the sudden increase in funding for space programs when the Russians successfully launched Sputnik. The possibility of a similar unanticipated stimulus in any given field always exists. The only criterion should be: Can there be further progress? and a "no" should be registered with extreme circumspection.

Mr. Horgan fails to overcome a fundamental bar to proving his thesis. It even seems vaguely that he does not try too hard. This problem resides in the distinction between quantitative and nonquantitative sciences. The fact that mathematics is employed in various sciences such as some branches of social science and economics does not make them quantitative. The predictive power of economics, e.g., is best described by Paul Feyerabend: "Prayer may not be very efficient when compared to celestial mechanics, but it surely holds its own vis-à-vis some parts of economics." The problem is that if a particular discipline is essentially qualitative, then any judgements about it are necessarily qualitative. At best, only a speculation can be advanced that it has reached its limits. Persuasive though the arguments may be, they can hardly be conclusive. This situation pertains in all the areas he covers save physics and cosmology. This is certainly manifest in the chapter on neuroscience. While it explores nicely some of the conflicting opinions in this area, all it does is emphasize how wide open the field is. We seem not to have a clue to the solution of the problem of consciousness or self-awareness. Are there no breakthroughs to be made here?

Only in the chapters on Physics and Cosmology is there the necessary quantitative structure to make clear judgements and even here they remain questionable. In the early part of the book reference is made to *The Answer* [author's emphasis]. In physics this is the Holy Grail, the modern search for which was initiated when Einstein sought to unify his theory of gravitation, i.e., general relativity, with the classical electrodynamics of Maxwell. The effort was never successful, but the concept of unification has been a driving force for physicists ever since. To the two forces known to Einstein when he initiated the search there are two more fundamental forces: the "weak" forces which mediate the nonelectrical interactions of electrons and positrons and the "strong" force which governs the interactions of protons, neutrons, and the even heavier elementary particles. There was a recent suggestion that there might be a fifth force, but sufficient negative experimental data killed that possibility.

Progress has been made. Electrodynamics and the weak forces have been unified into the "electroweak" force. Then there is the so-called standard model for unifying the electroweak force with the strong forces. The result is a theory with remarkable predictive powers but with too many troublesome loose ends to be considered the last word. It has too many adjustable parameters. One recalls Eugene Wigner's justifiably contemptuous dismissal of free parameters: "Give me one parameter and I'll draw you an elephant; give me two and I'll make its tail wiggle." This has been seriously addressed in the so-called Grand Unified Theories or GUTS, but even these have drawbacks. There is much yet to be done, and the absence of a clue as to how it is to be done is no reason for pessimism. String theory is one of the regions being explored, not the least reason for which is that it would include the gravitational force and provide the masses of the elementary particles. It has yet to produce other than tantalizing hints, but that is scarcely a reason to be pessimistic.

Horgan suggests that progress will die away because the questions have become unanswerable. There may be two reasons for such a situation to arise. The first is that the questions are intrinsically unanswerable and the other is that the experimental data on which theoreticians feed will not be available. As H. M. Georgi, the distinguished particle theorist, has put it: "The progress of the field is determined in the long run, by the progress of experimental particle physics. Theorists are, after all, parasites. Without our experimental friends to do the real work, we might as well be mathematicians or philosophers." More and more data at higher and higher energies are what Dr. Georgi refers to. The higher the energy the larger the accelerator. Here we have seen Congress terminate funding for the huge Waxahachie machine. And even if it did not there is no guarantee it would have provided all the information needed to make decisive progress. Money provides possibility not guarantees. And even if limitless money were available, would the ultimate globe-circling accelerator ever be built? There are many open questions here, including the idea that the whole structure may take a different form. None of these questions is intrinsically unanswerable.

Cosmology is the study of the structure and dynamics of the universe on a global scale. Here Mr. Horgan has a stronger case. It also is quantitative, but there is an important difference. Data are obtainable only by observation. We cannot, as in particle physics, run an experiment to obtain some specific information. We must take what the Hubble telescope and our radio and optical telescopes provide. Our only choice is what we will observe and record. To this we adjoin elementary particle interactions as being important in understanding the initial phases of the "big bang." There are several things to be understood about cosmology. The only force at work in this domain is gravitation. Both the weak and strong forces are short range. Electromagnetic forces, which are long range, cancel out by virtue of having both attraction and repulsion. Thus, cosmology is discussed solely within the context of the Einstein theory of general relativity. A cosmological model is then nothing more or less than a solution of the Einstein field equations. As observations are refined so will be our ability to distinguish and select a best candidate among the various models. We will be able to decide whether the presently observed expansion will continue or the universe will reverse and contract to a big crunch.

Cosmology, thus, stands or falls with Einstein's general relativity. This is not a stable configuration. General relativity is a classical theory, and there is little doubt that it must be quantized. Despite massive effort this has not been successfully accomplished. There seem to be as many schemes to this end being pursued as there are pursuers, and there is no consensus. This leaves open the possibility of a successor theory to general relativity being found one day. In this case the problems of cosmology are once again open to reconsideration.

Mr. Horgan is acutely aware that looking over his shoulder as he and the people he interviews judge science to be entering its twilight years is the similarity of this judgement to that made almost a century ago. It is said that when Max Planck started his doctoral studies in the late nineteenth century he was advised by his mentor that there was little more to be done in physics beyond tying up some loose ends and that everything was well known and understood. In 1894 at the dedication of the Ryerson Physical Laboratory at the University of Chicago, Albert Michelson said, "The more important fundamental laws and facts of physical science have all been discovered, and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote . . . Our future discoveries must be looked for in the sixth place of decimals." Mr. Horgan reproduces this prediction in order to refute it. That he does not do convincingly.

It is well known that physicists who make groundbreaking discoveries do so in their twenties and early thirties. They will thereafter always be competent at the highest level, but great discoveries will be for other, younger physicists to make. It is thus questionable that the elder statesmen of the discipline are the best qualified psychologically to make predictions about great new discoveries just beyond the horizon. They will not be the ones doing the discovering.

No, the verdict must be Not Proven.

Nonetheless the book is well worth reading. For each of the fields covered, apart from the last two chapters and the epilogue, a very fine state-of-the-art overview of the subject at the technical level of *Scientific American* is presented. They are well focussed and very effective if somewhat idiosyncratic—idiosyncratic in the sense that there is more of Mr. Horgan than would be manifest in a straight question-and-answer format. This is in no way objectionable. It provides a certain spice. In some instances his report seems a debate. Without doubt, an expert in any one of the fields will find something objectionable, but not of sufficient importance to vitiate the entire chapter. For instance, in the Introduction there is the statement: "Many physicists, beginning with Einstein, had tried and failed to fuse quantum mechanics and general relativity into a single, seamless 'unified' theory. . . ." This is incorrect. Einstein's attempt at unification involved general relativity and classical electrodynamics. These are minor matters. The nonexpert in any of the disciplines treated might expect to profit as well as enjoy reading the book. It is supple, well written, and glides smoothly past the mind's eye.