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Book Review

John Horgan, The End of Science: Facing the Limits of Knowledge in the Twilight of the Scientific Age. xii + 322 pp., bibl., index. Reading, Mass.: Addison-Wesley, 1996; New York, Broadway Books, 1997 (pb, with a new Afterword). $15.00.

"I am neither a prophet nor the son of a prophet" was the wise disclaimer of the biblical Amos (7: 14); John Horgan, on the other hand, has taken on the task of prophecy with less hesitation, and what he has prophecied is nothing less than *The End of Science*. There is precedent for this. Famously – and, with hindsight, ludicrously – Albert Michelson in 1894 expressed the opinion that "most of the grand underlying principles [of science] have been firmly established and... further advances are to be sought chiefly in the rigorous application of these principles.... An eminent physicist has remarked that the future truths of Physical Science are to be looked for in the sixth place of decimals" (Badash, 1972). (Common opinion identifies the originator of the remark about the "sixth place of decimals" as Lord Kelvin. Strangely enough, however, Horgan [p. 19] makes a major point of asserting that this common opinion is unwarranted, that "historians have found no evidence that Kelvin made such a statement." The evidence we do have – see Badash [1972], which is among Horgan's citations – is a statement by Robert A. Millikan [1950], who had heard Michelson's 1894 address: "Michelson... quoted someone else... I think it was Kelvin... as saying... that future progress was likely to be found in the sixth place of decimals." This is not airtight evidence, but neither is it "no evidence.")

More recently, in the 1960s, Gunther Stent (1969, 1978) made a similar argument for biology, which I would represent as follows: For the last 300 years, biologists have been seeking the secret of life; with the discovery of the double helix structure of DNA and the deciphering of the genetic code and its operation, the secret has been found, and all that is left is to "iron out the details" (see also Horgan, p. 10). Stent's views, to which many biologists assent, provide a point of departure for Horgan's book, with Horgan emerging as a disciple of Stent. Also in the 1960s, a somewhat similar argument was made for the physical sciences, by Alvin Weinberg (1967). Weinberg argued that the search for the basic building blocks of the universe, the ultimate elementary particles, although not necessarily at an end, had become irrelevant to the world we live in and divorced from other sciences. (Cf. Stent, 1969, 112–113.) Horgan, although not referring to Weinberg, makes a similar argument for particle physics in the 1990s – that, for example, in discourse concerning superstring theory, touted as the ultimate theory, we have gotten so far away from the real world and meaningful empirical verification as to have gotten beyond what we normally take as science. Thus far, I think there is some sense in the argument: Over the past 300 years, there has been a backbone of progress in both the physical and biological sciences that has been analytical and reductive – getting down to smaller and smaller constituents of physical and biological systems, seeking the ultimate building-blocks that form the foundation of our world. And also, over the last 300 years, this quest for ultimates has turned out to be quite relevant to technology and our everyday lives. In recent years, however, I would agree with Horgan (pp. 25–28), this heroic age shows signs of coming to an end: In biology, many would agree that we really have gotten down to the bottom. In physics, perhaps we have gotten down to the bottom with quarks and leptons, as some would claim, or perhaps the question of the ultimate particles has gotten away from our world, as Weinberg would claim, or away from science itself, as Horgan would claim; in any case, the search for the ultimate particles does not seem any longer to be able to function as the backbone of progress in the physical sciences and the technologies based on them.

Suppose we grant this argument – that the search for a certain kind of ultimate foundation has, in both the physical and biological sciences, come to some sort of resting place; where does that leave us? Here I would part company with Horgan. He takes the pessimistic view – that this signals the end of science. Horgan (p. 10; 1997) feels that the concern with ultimates, with foundations, with the big questions, is the interesting part of science. Yes, Horgan admits, to understand all of biology on the basis of the double helix is a large task that will not be accomplished anytime soon; and to understand all of the physical universe on the basis of our knowledge of the small particles that constitute it, and to translate this knowledge into useful technologies, is also a task whose completion is far from imminent. But these remaining tasks, according to Horgan, are just a matter of filling in the details, and are not really interesting science. In this, I would see Horgan as being in the position of one who came to a mathematician and asserted that once the axioms, the fundamentals of the mathematical system, had been decided upon, the rest of the mathematical endeavor – the development of mathematical structures and theorems about them – would be a matter of drudgery and detail, not of any great or fundamental interest. This would be to misunderstand mathematics. Similarly in the physical and biological sciences: even if we were to agree with Horgan that we have – perhaps, and in a certain sense – gotten down to the fundamental laws and the ultimate particles, there remains the open-ended and intensely interesting task of building up, from these foundations, the complexity of our world as it exists and the further richness of the world of systems and devices that can be imagined and constructed.

Building up the complexity takes place in what I would call the *synthetic* sciences – the sciences concerned with putting together an account of real-world systems, on the basis of known fundamental laws. Earth science is one of these: One does not expect that new principles of thermodynamics will be needed to deal with the high-temperature regime at the center of the earth, nor will new principles of hydrodynamics be needed to deal with weather systems on the surface. One will not need a new quantum mechanics to deal with the excited atoms of the ionosphere, or a new theory of the chemical bond to treat the cycling of carbon through the oceans and the atmosphere. Instead, earth science is a matter of "working out the details." Earth science is not coming to an end; indeed, it prospers: Along with associated and neighboring fields such as oceanography, meteorology, and space science (including solar system and planetary science), earth science is a burgeoning field, attracting bright young people, speaking to a popular audience, and garnering societal support because of its obvious relevance to the very practical question of the survival and flourishing of human life on earth. But earth science is not a part of Horgan's story, because it is not searching for new ultimates. Although earth science has seen some quite basic new departures, such as the theory of plate tectonics, this is not an ultimate theory of the type that interests Horgan: it is a middle-level theory, based on known fundamentals of thermodynamics, hydrodynamics, magnetism, etc.; and it is very much concerned with the particulars of earth history – the contingencies of the development of this particular planet – rather than the universal fundamentals of the universe at large.

Horgan's impatience with synthetic science is a matter of taste: He prefers the big questions, questions of "pure science, the quest for knowledge about what we are and where we came from" (p. 16); these large questions are especially relevant to the popularization of science, which is what Horgan does. The great majority of working scientists, however, are not going into the laboratory each day seeking some new ultimate. What sustains these people in their work is a real interest in what Horgan (p. 7) regards as details and what Thomas Kuhn (1962) calls puzzles – working out the logical structures of theories and their connections with experiment. There is an element of condescension in the attitudes of both Horgan and Kuhn toward the vast majority of scientists, who do what Kuhn calls "normal science," but their condescension need not be taken as normative: The success of the scientific tradition is very much bound up with its attention to both the foundational questions *and* the details; it is unfortunate that various outsiders looking in at science – including certain historians of science, philosophers of science, sociologists of science, and popularizers of science – have developed a distorted view of science that assigns far too much significance to the foundational side of the enterprise and far too little to the "details."

There was a third prophet of the 1960s who anticipated a part of Horgan's argument. Derek J. De Solla Price (1963), looking at indicators of the growth of science over the past 300 years, found an exponential growth pattern, the projection of which into the future would soon result in the absurdity of a population of scientists greater than the total number of men, women, children, and dogs. (Horgan quotes Bentley Glass for a similar argument.) Price's conclusion was that the growth pattern of science would have to change, and this change has by now taken place: the population of scientists and the resources at their command are no longer growing at an exponential rate. From Price's account, one might anticipate that if the transition to the new growth pattern were well managed, science could remain healthy; but if the transition were poorly managed, the result could be instability and disaster. Within this framework, I would view the decision to scrap the superconducting supercollider as a good decision, displaying the kind of realistic management of scientific resources that will enable us to deal with the end of exponential growth in a way that will avoid the instabilities inherent in gargantuan projects that devour large chunks of the total science budget in single gulps. Thus, while for Horgan the death of the superconducting supercollider, and the limitation of societal support and scientific growth that it signifies, are harbingers of the end of science, the framework suggested by Price's analysis allows for a more optimistic assessment: what we are seeing is a necessary adjustment to the requirements of the sustainable practice of science in the post-exponential-growth period – thus allowing for the continued flourishing of science, albeit with a lesser growth rate.

The scientific enterprise, then – even if we grant Horgan's scenario of no new ultimates and and no more exponential growth – need not be regarded as having come to an end: pursuit of the open-ended possibilities of synthetic science and practice of appropriate discipline in the use of scientific resources can defeat the negative implications of this scenario. Beyond this, is Horgan's scenario of no new ultimates fully convincing? Have we really already discovered all of the fundamentals – as asserted by Michelson and Kelvin in the 1890s, and by Horgan now? Might we, in fact, find superstrings – or something else – at the next level down in particle physics? Might the problem of consciousness become accessible to science in some way? Might the conundrums of quantum mechanics be resolved in some future theory? Horgan considers these questions and gives the pessimistic answer: No. His pessimism on this question seems to have various sources. First, Horgan has, over the past decade, been talking to a variety of people about a series of hard questions on the frontiers and fringes of science – quantum theory, consciousness, Gödel's theorem, parallel universes, superstrings, quantum foam, and the like. These are indeed hard questions, and the answers that Horgan has gotten from his various interviewees are not answers at all – they are guesses and conjectures, which are opaque and contradictory, confused and confusing, troubling and unconvincing. Horgan has come away from this with a sense of intellectual indigestion – which he transmits quite successfully to the reader. His conclusion is that all of this goes nowhere: there is no future for science on these frontiers. But this is an unfair conclusion. The situation on the scientific frontier has always been confused and muddy, and progress has come out of this – clarification has taken place – in ways that could not have been anticipated. To take a recent example, Alvin Weinberg's pessimism concerning particle physics in the 1960s may well have been related to the contemporary confusion in that field: there was a proliferation of elementary particles – the "nuclear zoo"; there was no single, fully convincing plan in the field for making order of this mess; and a certain feeling of weariness and pessimism had set in by the early 1960s. But then, beginning in the middle and later 1960s, quark theory was developed, and the nuclear zoo was brought under control, beautifully and convincingly. One cannot know the future, and one cannot confidently predict that all conundrums on the frontier will ultimately be resolved as neatly as the particle zoo; but neither is one justified in the opposing, pessimistic prediction.

A second element in Horgan's pessimism concerning the possibility of finding new ultimates relates to one of the central themes of the book, the idea of "ironic science." Horgan (pp. 7–8) believes that one ultimately gets to a level in science where further theorizing gets beyond the reach of "empirical science" and becomes an aesthetic enterprise, more like literature than like traditional science (cf. Weinberg, 1967). Superstring theory – a theory of structures much smaller than the observables of particle physics – is taken as a central example of this. Once again, however, history provides cases that argue against Horgan's pessimism. In the nineteenth century, many scientists believed that atomic–molecular theory was exactly what Horgan calls ironic science, that atoms and molecules were fictions or romances, concerning a supposed level of reality that was clearly – so these scientists asserted – permanently inaccessible to direct experiment. Theories at this level – these scientists and philosophers believed – could be justified only on indirect or aesthetic grounds, such as their ability to organize a certain range of data on the basis of simple assumptions. In fact, however, thoroughly unanticipated advances in the period 1895–1915 led to the possibility of detecting atomic-level particles and events one by one – as in scintillation counting, the Millikan oil-drop experiment, the Wilson cloud chamber, and the Geiger counter – and what had before been seen by some as mere hypothesis was assimilated to "empirical science." It is hard to know ahead of time just how far the reach of "empirical science" can be extended, but I think it helps to be aware of cases in which theories that could be supported initially only on indirect, hypothetico-deductive grounds, eventually became susceptible to direct verification, in unanticipated ways. Of course, some hypothetical entities, such as the ether in the nineteenth century, did not pan out, and superstrings may turn out to be in this class; but it's hard to know in advance.

A final element in Horgan's pessimism concerning the possible future discovery of fundamental novelties is his view of the progress of science as a matter of successive approximations: first the broad outlines are roughly sketched, then finer and finer details are filled in. In this view of the progress of science, once the basic outlines have been discerned – as has already happened, according to Horgan – there are no more "big" things to be discovered, only fine details to be added to the picture. This was exactly the view of the nineteenth-century scientists – that they were converging on the truth in this way. One of the things they did not anticipate, however, was the discovery of a new level of physical phenomena – the subatomic level – with radically new fundamental laws, as ultimately codified in quantum mechanics. Historians and philosophers of science have, indeed, in recent years quite completely given up the successive-approximation view of the history of science; Thomas Kuhn's views on the radical nature of scientific revolutions have been central in these developments. Even if one does not follow Kuhn and his successors all the way in their assertion of the radical "incommensurability" of successive scientific paradigms, I do not think there is any serious possibility of going back to the successive-approximations view that Horgan seems to espouse. Thus, there is no justification for writing off the possibility of the emergence of significant, radical novelty as a result of future scientific activity.

Although pessimistic, *The End of Science* is amusing; the fun, however, is mainly at the expense of the scientists interviewed, whose personal appearance, and behavior under journalistic grilling, provide the occasion for much mirth. Karl Popper, for example, "kneaded his temples and gritted his teeth as if in agony" during the interview, while David Bohm "kept smacking his lips," and Marvin Minsky "fidgeted ceaselessly, blinking, waggling his foot"; Clifford Geertz, in the process of "fidget[ing] incessantly," "now and then . . . pulled the top of his sweater up over the tip of his nose, like a bandit trying to conceal his identity." Murray Gell-Mann "wore a huge sardonic grin, as if he could scarcely contain his amusement at the foolishness of those who might disagree with him"; Edward Witten would "br[eak] into convulsive, hiccuping laughter as some private joke flitted through his consciousness"; Mitchell Feigenbaum "laughed maniacally"; and Freeman Dyson "snorted through his nose . . . like a 12-year-old schoolboy hearing a dirty joke." Hans Moravec "emitted an almost continuous, breathless giggle, whose intensity seemed proportional to the preposterousness of what he was saying," while Charles Hartshorne spoke in a "Mickey Mouse falsetto." Otto Rossler "had . . . a protuberant lower lip, and a bulbous chin," while Thomas Kuhn's "big lower lip . . . sagged," and Feigenbaum's "protuberant eyes bulged . . . from their sockets." Christopher Langton spoke "as he chewed on chicken fajitas"; Ilya Prigogine discoursed "between nibbles of his fish," and "one of his disciples . . . unburdened himself, in a lugubrious eastern European accent, of an impenetrable monologue." Frank Tipler is quoted in dialect: "Ah don't even drink alcohol! Ah like to say Ah'm the world's only teetotalin' Tipler!"

The reviewers ate it up: "keen observer"; "they all come to life"; "wicked eye for detail . . . zesty reading . . . hilarious" (front matter). The bottom line is this: Although scientists are no longer able to discover anything of interest to Mr. Horgan, they can still provide him with a good laugh.

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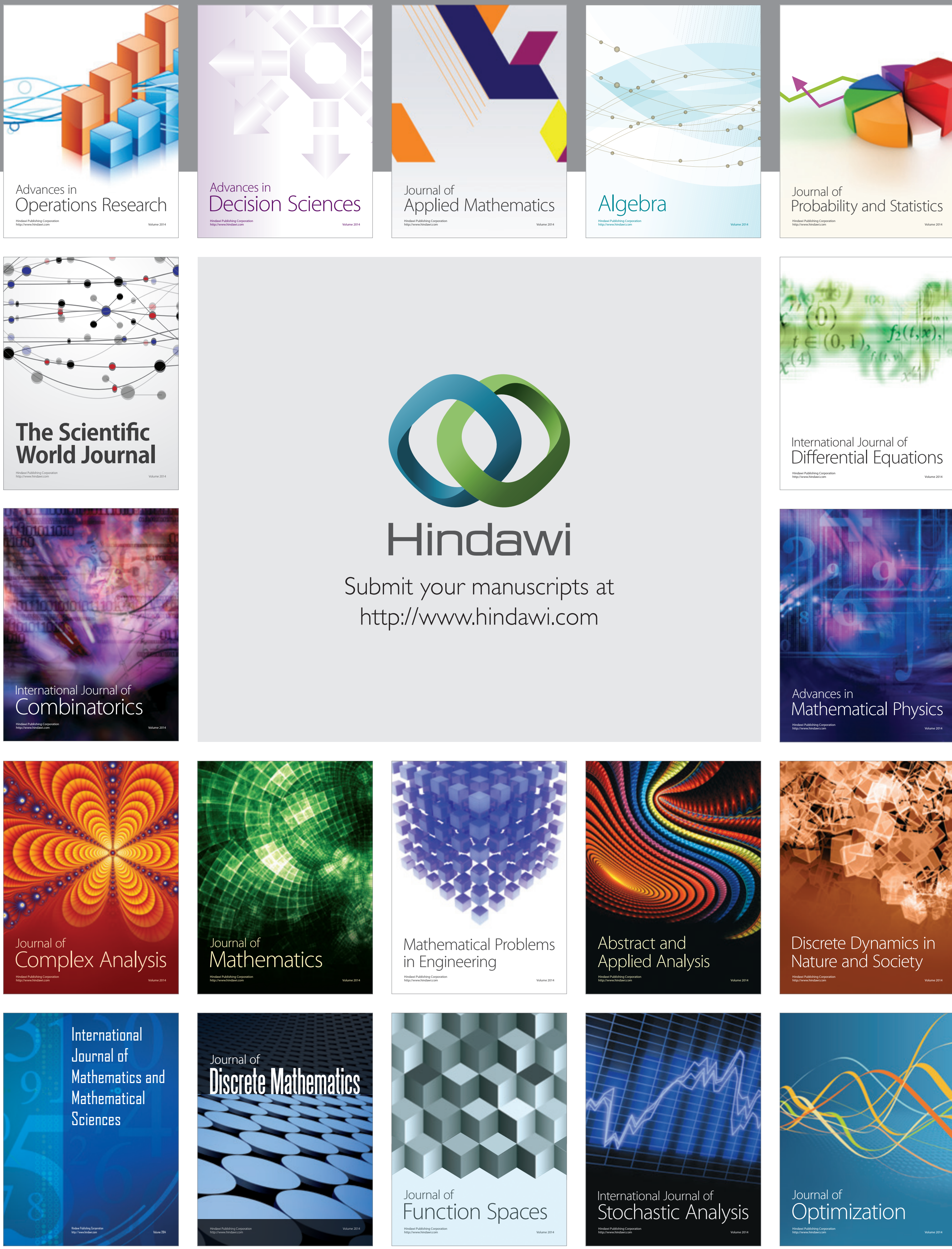
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