

A New Kind of Science

Stephen Wolfram

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Reviewed by Mohamed Gad-el-Hak

(Department of Mechanical Engineering,

Virginia Commonwealth University, Richmond, VA 23284-3015).

Reviewing *A New Kind of Science* is like stepping in a minefield. The danger lies in going against the deluge of praise, proving relevance to this audience, and arguing against the proposed new science that allegedly is set to replace science as we know it. Those issues will be addressed in turn, but first a brief background. Stephen Wolfram is considered by many to have been a child prodigy: first journal paper in particle physics at age 15; a stint at Oxford; Ph.D. from Caltech at 20; youngest recipient of the MacArthur Prize; faculty positions at Caltech, Princeton and Illinois; significant contributions to cellular automata and complexity theory; developer of the popular software Mathematica; and a successful entrepreneur, becoming a multi-millionaire at 30. Running his software company via e-mail and videoconference, Wolfram spent the last 10 years in virtual seclusion, relentlessly, tirelessly, secretly and nocturnally working on an idea that possessed him: generating complexity from simple computations, algorithms of only a few lines. The book, targeting both scientists and non-scientists, is partially about using simple rules of cellular automata to generate complex patterns. In this task the author has succeeded beyond reproach not only in showing that this can be done brilliantly and beautifully but also in explaining it lucidly enough for all to understand, appreciate and savor. In the opinion of several reviewers, including this one, this aspect of the book is a *tour de force* of clarity, elegance and simplicity. The problem is the huge leap the author takes in arguing that since nature is complex and many of the computer-generated complex patterns look or behave similarly to natural or man-made things all around us—a snow flake, a turbulent flow, a lung, a mollusk shell, a traffic jam, an outbreak of starfish on a coral reef, the entire universe—therefore that must be the way nature works. Nature runs its course the same way that a computer runs a program. That is the essence of the new science: cellular automata will yield all the secrets of the universe, solve our long-standing problems, and provide the theory of everything. More on that flight of fancy later.

The Deluge: The book was widely anticipated several years before its actual publication. Published on 14 May 2002, it quickly became an Amazon.com bestseller and was promptly reviewed by both the popular and scientific press. Heavyweights of the former included *The New York Times*, *Chicago Tribune*, *Newsweek*, *Time*, *The Daily Telegraph*, *Le Monde*, *Frankfurter Allgemeine Zeitung*, and *The Economist*. Except for the last, the popular press went gaga over the book, touting the author's claim of a new science that will stand existing science on its head. The *Economist* (p. 79, 1 June 2002) was more subdued even provocatively titling its review "The Emperor's New Theory." In the scientific press, the reviews were somewhat less glorious and more skeptical. In *Physics Today* (p. 55, July 2002), Leo Kadanoff's review was at once pointed, subtle and polite, concluding that he cannot support the view that any "new kind of science" is displayed in Wolfram's book. *Newsweek* (p. 59, 27 May 2002) quoted the famed physicist Freeman Dyson: "There's a tradition of scientists approaching senility to come up with grand, improbable theories. Wolfram is unusual in that he's doing this in his 40s." Kadanoff and Dyson express the minority opinion, however, with the majority of reviewers being excited beyond reason about the new science that will solve every human mystery including the currently depressed stock market, human free will, quantum field theory, and entropy. For the present reviewer, danger lurks in going against the deluge of high praise, but particularly doing so several months behind the reviewers who have already anointed Stephen Wolfram as the Isaac Newton of the twenty-first century.

Relevance: As *New Kind of Science* aims at replacing existing science, readers of *Applied Mechanics Reviews* have a significant stake in the matter. Mechanics—classical for the most part but occasionally quantum—is the underlying branch of physics upon which almost all of applied mechanics is based. The mathematics here is often in the form of partial differential field equations, where both space and time are indefinitely divisible continuum. For example, most, but not all, fluid flows can be described via the well-known, well-posed Navier–Stokes equations. In simple problems, those first-principles equations can be solved and agreement with experiment is beyond reproach.

It is the complex problem, such as a turbulent flow, that frustrated Wolfram and scores of scientists before him. The search for simpler alternative to the field equations is, therefore, quite alluring. The field equations of mechanics, when they can be solved, provide a powerful predictive tool to explain the mechanical world around us as well as to help design our man-made machines. When analytical solutions are unattainable, the field equations are discretized and brute force numerical integration is used. But even that is not possible for some situations, for example for realistic high-Reynolds-number turbulent flows and other multi-scale problems where the required computational memory and speed overwhelm today's supercomputers. For such impenetrable problems, a certain degree of empiricism is introduced to the first-principles equations and relatively faster computations can then proceed. Heuristic turbulence modeling is an example of such compromise. Despite those limitations, traditional science works exceedingly well and applied mechanicians happily practice their craft. Readers of this journal should, therefore, care passionately if the traditional laws of mechanics are to be supplanted by a new kind of science.

The Argument: Cellular automata were introduced in the late 1940s by John von Neumann and Stanislaw Ulam, although Stephen Wolfram claims to have independently discovered the tool three decades later. Cellular automata are discrete dynamical systems whose behavior is completely specified in terms of a repetitive local relation. The space continuum is represented by a uniform one-, two- or three-dimensional grid, with each cell containing a single bit of data, for example 0 or 1, red, white or blue, etc., a few bits of data, or even a continuum of states. The time continuum also advances in discrete steps. The state of each cell, or memory location, is computed at each time step from a simple algorithm in terms of its *a priori* defined close neighbors. Simple computer programs could, in fact, result in complex patterns. Stephen Wolfram particularly researched one-dimensional automata arranged in a line. The bit of data in each cell is updated at each time step based only on the value of that cell and that of its two nearest cells. Wolfram methodically studied such automata and identified a total of 256 different rules. Space-time diagrams of the bits generated show four distinct patterns: dull uniformity; periodic time-dependence; fractal behavior; and truly complex non-repetitive patterns.

Stephen Wolfram says that science has been broken for more than 300 years and that he can fix it. The 'errors' of Darwin, Newton and the other great ones will be corrected once and for all. *A New Kind of Science* proposes a radical notion about the development of the natural world, and Wolfram aims to uncover the fundamental rules underlying the complex universe. The pattern-generating capabilities of discrete cellular automata are to supplant the difficult-to-solve or even yet-to-be-found continuum equations of traditional science. But just because the patterns of cellular automata *can* resemble those of the natural world does not mean that nature *must* work that way. Furthermore, traditional equations are believed to represent reality because they can be used to make predictions that agree with observations. This is the essence of Galileo's paradigm that is the underpinning of modern science. The explanatory power and authority of science stem from its ability to make verifiable predictions, otherwise theory is a mere *post-hoc* speculation. That is exactly what the proposed new science is. The computer games of cellular automata provide mere *post-hoc* speculation and cannot possibly compete with the predictive horsepower of $F = ma$ or $E = mc^2$.

Wolfram's boasting, throughout 1200 pages, is at a minimum excessive. He writes, "I have discovered vastly more than I ever thought possible, and in fact what I have done now touches almost every existing area of science, and quite a bit besides." Wolfram writes of several ideas as originating by him, but in fact the credits belong elsewhere. Alan Turing conceptualized the simplest universal computer, the Turing machine. Thinking of the universe as a vast digital computer was the brainchild of Edward Fredkin. The use of a cellular automata machine as an environment for physical modeling was detailed by Tommaso Toffoli and Norman Margolus. Other ideas by Per Bak, Charles Bennett and Hans Meinhardt percolate throughout the present book but are not properly credited. Writing in the first person, relegating all notes to the last 350 pages of the book, grudgingly as well as dismissively mentioning few names, and restricting the list of references to his own publications, Wolfram does not help to dispel this important shortcoming.

Wolfram took the unusual approach of bypassing the peer review process. He self-published the present book, acting as author, editor and publisher. The opening paragraph in the mostly favorable *Time*'s review of the book (20 May 2002) is worth reflecting on: "Cranks are an occupational hazard that every scientist eventually faces. Fortunately, these characters are usually easy to spot. If someone claims to have a grand theory that overturns centuries of scientific knowledge—especially when the theory spans unrelated field like physics and biology and economics—the odds are good that he or she is a crank. If the author publishes not in standard scientific journals but in a book for general readers, watch out. And if the book is issued by the author rather than a conventional publisher, the case is pretty much airtight." *A New Kind of Science* claims are more extravagant than those of cold fusion—à la Stanley Pons and Martin Fleischman—and deserve proportionally more vigilant scrutiny. Wolfram has

not validated his theory nor has he subjected it to the peer review process like the rest of us mere mortals are expected to do. Furthermore, in contrast to the old kind of science, Wolfram's *anti-Newtonian* model of the universe cannot be used to predict much of anything. The new emperor has no clothes. The present book is an offense to all those who play by the rules and brick by brick build this edifice we call science, good old science.

The Bottom Line: For fun reading and pretty pictures, this book is not a bad recommendation. For inspiration, read Isaac Newton's *Principia Mathematica*, in Latin. For problem solving in applied mechanics, the Newtonian framework is still the best bet, and one's time is better spent reading traditional books and journals in mechanics.