JOURNAL OF APPLIED CRYSTALLOGRAPHY

ISSN 1600-5767

The Knowledge Machine: How an Unreasonable Idea Created Modern Science. By Michael Strevens. Penguin, 2022. Pp. 368. Price GBP 7.99 (Kindle), GBP 9.95 (paperback). ISBN 9780141981260.

John R. Helliwell*

Department of Chemistry, University of Manchester, Manchester M13 9PL, United Kingdom. *Correspondence e-mail: john.helliwell@manchester.ac.uk

Keywords: book reviews; history of science; philosophy of science.

This book exists in several editions, including some with the slightly different title *The Knowledge Machine: How Irrationality Created Modern Science* (Liveright Publishing/W. W. Norton & Company, 2020). I read the Kindle for iPad version of the Penguin edition subtitled *How an Unreasonable Idea Created Modern Science*. The author sets out 'to answer two big questions, one philosophical and one historical' with this book:

> How does science work, and why is it so effective?
> Why did science arrive so late?

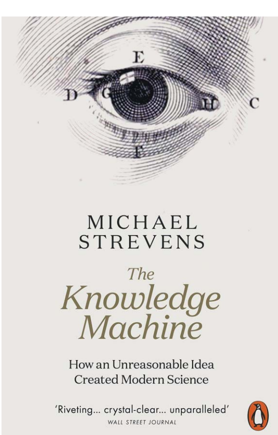
I think that these are good questions.

Chapter 1 starts with assessing Karl Popper's notion that 'science advances by falsification' versus Thomas Kuhn's that 'science's evolution is marked by paradigm shifts', whilst looking for a common theme. The author selects Popper's biggest idea as that 'scientific attitude is [a process] able to refute a theory, though unable to verify it.' Moving on to Thomas Kuhn's theory of how science works, Strevens comments that, whilst Popper had in effect celebrated the individual scientist's honesty, Kuhn offered a whole world view where a paradigm shift, indeed a complete overturning, could occur, being an example of a scientific revolution. Strevens uses the very well known example of the revolution that Copernicus brought about with the theory and supporting data that the Earth goes around the Sun rather than the (before then) preferred view that everything moves around the Earth, giving us a special role in the universe. The chapter concludes with three thoughts. Firstly, Popper and Kuhn agree in their different ways by acknowledging that theories can be toppled, one by falsification and the other by paradigm shift. Secondly, Strevens affirms the importance to both philosophers of experiment and data. Thirdly, he lays out his plan for the rest of the book.

Chapter 2 is entitled *Human frailty*. It has an intriguing sub-title: *Scientists are too contentious and too morally and intellectually fragile to follow any method consistently*. Strevens describes Eddington's selective use of data and a biased narrative. The chapter moves through more illustrative case studies to document the deliberately misleading use of science in industry (*e.g.* to continue selling cigarettes) or by great scientists like Pasteur seeking to deflect critics in insidious ways.

Chapter 3 is entitled *The essential subjectivity of science*. Strevens introduces the need for repeat experiments by citing Popper's view of the Eddington solar eclipse measurements and the magnitude of the bending of light. However, the infrequent occurrence of such an eclipse was a major obstacle. Whilst this is true, *there is no reason to rush* is surely the conclusion here. However, Strevens champions the notion that sometimes scientists have to 'make a judgement call—personal, instinctive, subjective'.

Part I concludes that, whilst Popper and Kuhn adhered to the view of science being capable of objectivity, Strevens considers that he has conclusively proved, with his selected historical examples, that it is not. He states that the success of science is 'the iron rule of explanation'.



Part 2 covers *How science works*. Chapter 4 is *The Iron Rule of Explanation*, with a subtitle *Enter the rule that defines modern science and gives it unprecedented knowledge-making power*. Two more historic characters are described in a case study on the nature of heat and are presented as 'actors of the iron rule of explanation'. One supports a caloric theory of heat and the other a kinetic theory. This leads to Strevens's explanation of his iron rule: ‘it directs scientists to resolve their differences of opinion by conducting empirical [tests] rather than by . . . philosophizing . . . ’. Well, yes indeed. More interesting and more subtle is the second requirement that the empirical test has to ‘decide between a pair of hypotheses, perform an experiment or measurement, one of whose possible outcomes can be explained by one hypothesis but not the other’. Strevens argues that explanation, which is vital, of the empirical measurements is not a prediction. (A lengthy footnote elaborates on when explanation and prediction are the same and when they are not.)

Chapter 5 is entitled *Baconian convergence*. Its subtitle is *How science’s consensus on procedure, enforced by the iron rule, leads to discovery*. Enter ‘what is the nature of heat?’ again. But there is a good description of how Bacon arrived at a hypothesis that ‘explains its occurrences, non-occurrences and its variations’. Bacon concluded that ‘The quiddity of heat is motion and nothing else.’ Strevens provides a rephrasing: ‘heat is the disordered motion—the vibration—of the small particles of which all things are made’. After that optimistic start, Strevens concludes that Bacon’s method is ‘impossible to apply in practice because there are typically several competing hypotheses of roughly comparable explanatory success’. I really do not see why that should be the conclusion because is that not what probability and likelihood are available for? Indeed, Strevens says as much in two important footnotes (7 and 8). (Why are they footnotes?)

Chapter 6 is entitled *Explanatory ore* with the subtitle *How explanation became objective, yielding the material to forge an iron rule that says the same thing to every scientist (the iron rule’s first innovation)*. A somewhat refreshing opening to this chapter is offered by conceiving what it would be like arriving at an Atlantis imagined as not having science or technology, where it is our job to explain all that. To add an interesting twist, the Atlantis students attending our course only believe ideas and facts that rhyme with each other. It proves to be an impossible job of course, but it is an interesting allusion, and elusion.

At this point of the book I check the back-page description again, versus the book’s title. It seems to be introducing a history of science treatise and not a philosophy of science book, in spite of the title. The book seeks to explain ‘Why did we take so long to invent science?’, and actually with its numerous historical case studies it does do that. The second question, ‘How has it proved so powerful?’, is less well answered.

Chapter 7 is *The drive for objectivity* with the sub-title *How the iron rule enforces objectivity in scientific argument while allowing pervasive subjectivity in scientific reasoning (the iron rule’s second and third innovations)*. First up, the interesting clash between the two 1906 Nobel Prize winners, Golgi and Cajal, on the nature of neurons. Then back to Eddington and the solar eclipse measurements. Following that, as a further case study, the various investigations of the shapes of snowflakes; controversy between scientists became accusations of the equivalent of photoshopping to realize more perfectly symmetric pictures.

Chapter 8 is *The supremacy of observation* with a subtitle *How the iron rule ejects everything from scientific debate but a theory’s ability to explain observable phenomena and how that came to be (the iron rule’s fourth innovation)*.

Part III is entitled *Why science took so long*. Chapter 9 is entitled *Science’s strategic irrationality* with the subtitle *Why did science take so long to invent? Because the iron rule looks like a terrible idea*. This chapter opens well with an interesting question: ‘What stopped him [Aristotle] from inventing modern science 2000 years before the scientific revolution?’ Strevens lists various significant incremental steps as examples which taken together make that leap for science beyond any one person’s imagination, such as Aristotle or those that followed. Even today, looking back on my own career and my imagination of what would be at different stages, I can say that my imagination could not match what has happened in the coalition of increments into leaps. Footnote 9 is interesting (again why is it a footnote?), briefly examining the assertion ‘Is philosophy really so useless to science?’ My view is that philosophy is useful because it attempts to systematize what is going on in science.

Chapter 10 is *The war against beauty* and its subtitle *Appeals to aesthetics have no place in public scientific argument, insists the iron rule. This ban on beauty is also an attack on reason: elegance often, if not always, points the way to truth.* It starts with ‘fire, earth, air and water’. Footnote 4 is a delightfully absurd example of Aristotle’s theorizing: creatures that he thinks should exist are as yet unseen on Earth because they are on the Moon. The chapter goes on to describe the development of particle physics. Strevens documents the prediction by Murray Gell-Mann, based on ‘preserving the beauty of the eightfold way’, and then the discovery at CERN of the omega-minus particle (see especially the experimental facts of the bubble chamber tracks in Fig. 10.13). Footnote 24 dissects whether aesthetics can be part of explanation. Gell-Mann’s idea of the eightfold way in particle physics seems like mathematics to me rather than beauty.

Chapter 11 is entitled *The advent of science* with a subtitle *Why, when science finally arrived, it was in Western Europe and not some other place and in the seventeenth century and not some other time?* The chapter embarks by contrasting stone age tools versus modern science: perhaps an odd juxtaposition, but it emphasizes the role of sophisticated instrumentation, and computers, in modern science. Without technology’s push where would science’s pull get to? Not very far, is my answer. The chapter elaborates a tribute to Isaac Newton in effecting ‘glorious discoveries carved out by Newton’s narrowly empirical method’. The chapter concludes that ‘it was the seventeenth century that made modern science’ with Issac Newton as the catalyst.

Part IV covers *Science now*. Chapter 12 is entitled *Building the scientific mind* with a subtitle *How ordinary humans are transformed into modern scientists through a morally and intellectually violent process*. This offers an interesting insight into Strevens’s mind when considering the training of young scientists: ‘Perhaps you could explain to them that nonempirical thinking—appeals to metaphysics, God, beauty, and the like—is bad for science.' Surely the point is instinctive that a science trainee wants to learn how to find out, satisfying their curiosity about the world, and with such a skill there may be a satisfying job at the end of one's training. It is important though to state that, as emphasized by Max Perutz in his book '*Is science necessary?* (p. 193), finding things out is necessary for a scientist, but the thing that separates a scientist from a detective is a curiosity about the natural (rather than criminal) world.

Chapter 13 is entitled *Science and humanism* with a subtitle *The fullness of humanistic thought against the poverty of scientific thought; the effectiveness of scientific thought against the impotence of humanistic thought*. This chapter includes the statement 'Science is not a culture, it is a rule book'. Furthermore, he illustrates the clan of us scientists by showing the 1768 painting of the death of a bird by depriving it of oxygen (Figure 13.2).

Chapter 14 is entitled *Care and maintenance of the knowledge machine*. This chapter, whilst in Part IV *Science now*, kicks off with the 6th century BCE. The author justifies this by describing the microcosm of Miletus's abuse of its natural habitat and then comparing it with the macrocosm of the whole Earth and the challenge of climate change today and how to address it by mobilizing the science community. He seems to see no need to mobilize the better behaviours of all countries and all the individuals that constitute those societies. Basically, I would say that politics and policies do matter and, suffice to say, the task of containing climate change surely cannot be dumped on scientists alone.

At the end of the book, Strevens prescribes three things that he sees as needed for the future for science: 'a fighting spirit, apply the 'iron rule of explanation' and leave science alone free of tinkering by funding bodies, technology companies or political actors'. Yes, one could support those ideals. Then, we come to the final page: 'science is not a machine, it is a social institution'. So, this would presumably be a better title for the book?

There then follows a useful, short, *Glossary of novel terms*. There is an extensive set of footnotes to the chapters and likewise a large set of references. The book concludes with an index. On a technical point, the reading of the book and navigation between chapter footnotes is very easy in Kindle for iPad.

The author obviously is a very erudite historian, and philosopher, of science. We learn of him, 'Michael Strevens, a 2017 Guggenheim Fellow, is a professor of philosophy at New York University. He was born in New Zealand and has been writing about philosophy of science for twenty-five years. He lives in New York.' I expected from the book title an analysis of science as a 'knowledge machine' today, and that did finally arrive when we got to Part IV. The back cover of the book makes clear that he seeks to explain the steps over the ages as the route taken to get to this stage. So, in terms of recommending the book for purchase, it depends on what you the reader of this review might want of the book. There is much on the history of science. There have already been a lot of reviews of this book as judged by the Amazon website, an important metric of the impact of the book. I found it a thought-provoking read.