Thinking Scientifically about *Scientifically Thinking*

Review of “Scientifically Thinking” by Dr. Stanley A. Rice, Prometheus Books, 2018

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It has been a great pleasure for me to read, and review, *Scientifically Thinking* by Dr. Stanley A. Rice. First of all, let me state that Dr. Rice has written a lovely book, and I do sincerely mean that it is lovely, in each of the nuanced meanings of the adjective. It is clear exactly what kind of scientist Dr. Rice represents – the kind who has never lost the sense of wonder and exploration more associated with the magic of childhood than the learned intellectual numbness of later life. Like most good scientists, Stanley Rice is a curiosity driven problem solving explorer of nature, who becomes more enthralled with each observation he makes, and exponentially so with advances in mechanistic knowledge. He is an addict, through and through, and the joy and exuberance of that addiction becomes clearer with every page of this book. The term lovely also applies to not only the love that Dr. Rice has of science, but also how he frames the very scientific approach as an act of love itself, love of nature, love of Earth, and love of other humans. Moreover, he sees the act of sharing science to be an act of love. This is nowhere more clear than in the epilogue where he writes “I think I can summarize my life’s work…as throwing open the windows of these hallowed halls and inviting people to enter, or at least to look in, to let the winds of public curiosity blow away the incense of scientific mystique.”(p.228) He eschews the common notion that mechanistic reduction removes the wonder and magic from the world, and demonstrates just the opposite. In his words, “Natural laws help us understand the world so that we can see its beauty and wonder” (p.229). Throughout this book Dr. Rice’s energy and enthusiasm are infectious; in this regard, it was a joy to read this book.

The merits of this book notwithstanding, it is my view that Dr. Rice dances on the edge, if not falling outright into the regrettable trap of scientific imperialism – the idea that science is a superior way to approach all things, and if only more people thought scientifically, then the world would instantly improve. To be sure, science has made more progress than any other approach with regards to predicting and controlling nature and natural phenomena. This should be no surprise, as predicting and controlling natural phenomena is precisely the job that science has been developed and refined to perform. However, the history of science shows us that while science makes much technological progress and that theories of understanding are very useful, scientific understanding often turns out to be wrong. Even theories that are extremely useful in predicting and controlling nature (e.g. Newtonian Physics once seen as the greatest possible human intellectual achievement) also turn out to be wrong. Newtonian physics is not just a particular case of Relativity Theory that happens when things are not moving extremely fast, the construct of the universe, including time and space and their relation, are simply incorrect in Newtonian Mechanics (at least as per our current understanding).

Given the history of science, the evidence that a theory’s success provides to justify the actual existence of its unobserved hypothesized things and associations (a branch of philosophy of science called Realism) seems difficult to justify, although some have tried and are still trying. It seems highly unlikely that our scientific theories are a certain path to truth and the Big Questions (BQ) as Dr. Rice calls them, and due to problems of affirming the consequent and underdeterminism of theories, may be no path at all. Yet, he goes so far as to make the claim "Philosophers and theologians think they have the Big Questions arena to themselves, especially when it comes to human nature. However, science not only addresses the Big Questions but also has for centuries been conquering BQ territory from which philosophy and religion have had to retreat." (p.181). In my view, this position, is as absurd as it is unjustifiable. Moreover, it is a damaging and dangerous stance to take. Science has far too long attempted to put itself on an epistemic pedestal, making hyperbolic claims that it cannot possibly live up to, and in doing so losing all credibility when it fails, as it must do at least from time to time. Moreover, from the view of scientific pragmatism, a scientific theory is a good theory if it works, but the underdeterminism of theory by data leads us to a position that no matter how well a theory works, one cannot conclude its underlying premises and theoretical claims are true. It is a direct manifestation of the fallacy of affirming the consequent, and the author ignores this entire issue, blissfully shouting scientific imperialist rhetoric that is just as dangerous as fanaticism of any flavor.

To be fair, the author does a good job of explaining, in very general terms, that human thinking is saturated with error – that in the author's words, "Our brains are the amphitheaters of delusion" (p.16). He details how human minds did not evolve to find truth, they evolved to survive and reproduce – and in many cases believing a false thing may give an evolutionary advantage. We tend to focus on a very small number of observations and ideas – the explosion of the information age has only made this worse and not better. We have a hard time appreciating a large-scale perspective, and we miss trends by focusing on small bits of information – e.g. rejecting climate change based upon a few days of weather. The author then gives us good news. A remedy to this problem already exists and is available to us right now, right in front of us. It is the Scientific Method. Not to worry, the author is not suggesting we all become professional scientists – rather he posits that the scientific method is, like delusion and illusion, also a part of normal human thinking and that all we have to do is properly coax it out in order for it to emerge in each of us. The author's goal is to show us that scientific thinking is simple, is just "organized common sense" to quote Huxley, and that if you can nourish the scientific parts of your instinctual thinking while learning to keep the bias and illusion out, then you will be able to, as the title claims, "Liberate Your Mind". Setting aside the above criticisms regarding scientific imperialism, let's focus on the authors project. The author is attempting to describe to a lay audience what science is and how it works. As such, he inevitably is compelled to address what distinguishes science from non-science, which has classically been called the "problem of demarcation". This is the search for a clean definition that distinguishes science from non-science, in terms of necessary and sufficient properties, and it has long eluded philosophers and scholars of science despite vigorous attempts to find it.

Having framed the need to understand what science is, so that we can all do more of it, Dr. Rice presents a very traditional and simple view of the scientific method, one each of us may recognize from what we were likely taught during our middle school and high school education. One makes a claim about cause and effect (i.e. a hypothesis), one gathers evidence that tests the hypothesis (experiments), and then one uses the evidence to determine if the hypothesis is true or false – and that is it. Rice posits that it is actually that simple – at least in its abstract form. It is a formula for truth, a knowledge crank that one can turn over and over again and understanding will just pop out. It should be noted that the author certainly makes some additional essential observations about science. That evidence must be "public" is key – it must be something external to the person that other people can observe and check for themselves – this is how science can be self-correcting, also a key component. The author also correctly points out the irony that "science liberates your mind by constraining it". What does that mean? It means that by constraining thought to what can be tested by observing the natural world, one reins in the delusion and illusion and imagination to focus on what actually is – not what might be, not what could be, but what is.

To his credit, the author does then proceed to show how much more complex science really is than his earlier description – as he must. The author very appropriately softens his earlier view of the simplicity and methodological certainty of science in several important ways. He acknowledges, upfront, that scientists are as biased as anyone else and that one cannot even make a measurement without bias creeping into the measurements. The author makes the acute point that "one could say that the process of science is just a formalized way of trying to think of all of the things that could go wrong in research –such as bias and invalidity—and to try to correct them" (p.132). Dr. Rice references scholars who have claimed up to 235 potential sources of bias in scientific research and devotes a large part of the book (section II) to exploring some of the most important biases. He touches on issues of the distortion of the world by our senses, not only direct misperception, but also chance distortions of observation of frequency and/or association that can be addressed by statistical considerations of means and distributions (chapter 6). He describes additional challenges including the problem of humans thinking in linear functions and having a hard time grasping geometric progressions (chapter 7), problems of categorization (chapter 8), issues of correlation vs. causation (chapter 9), tendencies of humans to see intelligence and agency when none is there (chapter 10), and issues of validity of model systems and experimental settings (chapter 11). He includes a discussion of confirmation bias, and demonstrates that it is known both within and outside of science by referencing a fantastic quote from Henry David Thoreau "We cannot see anything until we are possessed with the idea of it and take it into our heads---and then we can hardly see anything else."(p.67). He goes on to acknowledge cultural and anthropological differences, such as studies in which people from different cultures, when presented with the same picture, will examine different parts of the picture (p. 67).

But wait a minute. If the above is all true, then how can evidence (which is saturated by bias) be used to determine true hypotheses, as the author earlier argues to be the fundamental characteristic of science? The author develops the argument that scientific method serves the purpose of remedying these biases. To the author's credit, he goes into considerable and artistic detail explaining why human observation is flawed. He explains why uncontrolled observation in the natural world is inevitably imbued with endless confounders, and illustrates how the purpose of experimentation is to tame these confounders, to isolate variables, to infer causality (where otherwise only correlation can be observed).

Consistent with the rest of the book he gives lovely examples of clever experimental interventions to test specific hypotheses, such as the extending or shortening of the legs on ants in order to test their abilities to navigate based upon number of steps taken (p.51). This is just one example, and the author gives many delightful instances – again, the very lovely part of this book. He also illustrates to the reader that humans may not accurately observe, or reason about, that which is right in front of them and that much of science is focused on compensating for these intrinsic errors in human observation and thinking. So, by the author's own description, science is not a simple process of elimination where one has to only hypothesize, test, and reject theory after theory until one arrives at the truth of the matter, the only hypothesis that persists despite scrutiny. It cannot be this simple because the testing and observing is contaminated with all manner of human flaws in observation and reasoning and as such, while the logical underpinnings may be simple, the science itself can be hard.

Dr. Rice correctly introduces that there is a logical structure through which science works, which contains its own slings and arrows, and the understanding of which is essential to both the practice of science and the assessment of scientific claims. In this regard, he proceeds to tackle the demarcation of science from non-science from several points of view. In particular, the author focuses on Popperian falsifiability as a necessary criterion for science. If there is no evidence that could reject a hypothesis, then it cannot be scientific. However, he also goes on to argue that a characteristic of science is that hypotheses are easily ruled out once contradictory data is obtained. This is a complicated topic, and in some ways a sticky wicket of scientific philosophy – still, in my view the author fails to mention that science does not work this way because hypotheses do not exist on their own – they exist in what Quine called a "web of belief". There are endless background assumptions, often unknown to (or at least unconsidered by) the scientist, that are always present. This affects scientists and non-scientists alike.

Lord Kelvin (amongst the most famous physicists to have ever lived) was able to firmly reject Darwin's theory of natural selection, because the Earth simply wasn't old enough. His determination was based upon measuring the heat of the Earth at his time and determining the rate at which it was cooling – in doing so, he could provide an estimated age of the Earth based upon sound scientific observation and theory. However, there were many background assumptions (what Quine called auxiliary hypotheses) baked into his calculations – one of which that there were no other hitherto undiscovered sources of heat strong enough to alter the temperature of the entire planet. This likely seemed an extremely safe assumption to Kelvin; after all, wouldn't something that substantial already have been discovered. Yet, not much later, radioactivity was discovered – a hitherto undiscovered source of heat strong enough to alter the temperature of an entire planet! The discovery of radioactivity rejected Kelvin and "unrejected" Darwin by changing the estimated age of the Earth. Thus, as clean and elegant as Popper's thoughts may have been at the time, they just don't hold up, and have been known not to hold up for decades. Indeed, even Popper himself was well aware of this problem and wrote about it specifically – calling background assumptions "ad hoc hypotheses". Some have suggested that science can be differentiated from pseudoscience by how auxiliary and ad hoc hypotheses are approached and treated. However, that any hypothesis can be rescued from rejection, no matter how damming the evidence, by evoking a particular auxiliary hypotheses is clear. This must be taken into account in any fair description of science, and cannot (as the author has done), simply be ignored.

Perhaps as important as the logical structure of a web of belief is the way that actual scientists act. They may not reject hypotheses even in the face of clear evidence that gives obvious contradiction, nor are they rational Bayesian machines that objectively weigh evidence. Certainly, few would label Galileo Galilei as a pseudoscientist, and yet his version of Copernican theory should have been soundly rejected based upon the lack of a parallactic shift, lack of a 1000-mile wind at the equator, and that cannon balls fired in different directions went the same distance – observations that firmly rejected a model in which the Earth had to rotate on its axis at 1000 miles an hour (at the equator) and given the understanding of physics at the time. He evoked auxiliary hypotheses in response to some of these objections (e.g. the stars must simply be much farther away than previously thought rendering the parallactic shift undetectable), and simply ignored the rest of the contradictions. The fact that he ultimately turned out to be correct is irrelevant to the logic of how he practiced. Turning to Charles Darwin, whom Dr. Rice holds in particularly high esteem, Darwin's ideas and their development do not line up with the Popperian program either. In other words, there was lots of disconfirming evidence that clearly rejected natural selection. First, as above, Lord Kelvin's careful and thermodynamically determined age of the

Earth was far too young for natural selection to have occurred. Second, understanding that offspring were the average of paternal traits meant that any mutation that conferred an advantage would be "washed out" by subsequent breeding, and could never emerge as a stable trait. These rejections were later rendered invalid once radioactivity was uncovered (changing Kelvin's calculations) and once an appreciation of dominant and recessive properties of certain genes were appreciated (eliminating washout objections). However, neither radioactivity nor dominance/recessive traits were known to Darwin. Darwin devoted an entire chapter of "on the origin of species" to the problems of the theory – so he was well aware of problems with his theory and yet he advocated it, albeit with appropriate and admirable circumspection.

So according to the author's definitions both Galileo and Darwin were pseudoscientists who continue to believe their hypotheses despite clear falsification by evidence that could compel rejection of the hypothesis. They were "deniers", as Dr. Rice describes those who refuse to see the truth despite the evidence. A proper analysis might include descriptions that science has a strong social component, that communities of scientists adjudicate how evidence weighs on theory. While the social aspects of science have all manner of epistemic implication (good, bad, and downright ugly) – one of the aspects is that individual scientists can be pseudoscientific deniers (as the author defines the term) while the scientific enterprise can be a Bayesian instrument of hypothesis rejection based upon evidence. It is precisely because Dr. Rice presents an unrealistic presentation of the epistemic simplicity of scientific claims that these problems cannot be discussed in his work – indeed, they are not really even raised at all. To be fair, at many other points in the book, Dr. Rice gives fine examples of science in which auxiliary hypotheses are at play and affect science – even in experiments he describes from his own lab. So, this issue is baked into the narrative of the book, but is it ignored in any formal description, favoring a view of science that is clean, logical, linear, and entirely inaccurate when considering the data we have on science itself.

Clearly, I find the above problems to be a serious flaw in this work – and in my view, potentially even dangerous. They propagate an unrealistic and imperialistic view of science that will only continue to facilitate misunderstanding of what science is by the lay public and perhaps even scientists themselves. I state this opinion with no small manner of pain and discomfort. First, this is of course, only my opinion – although I do believe it to be firmly grounded in scholarly work of others who study this issue specifically. Second, I agree with the author's quote that "Humans are always biased. All humans. Always" (p.139) – and in case the reader is not aware, by all evidence I do appear to be human, so there you have it. Third, I believe that the nuances of science can, in of themselves, be dangerous as they can be disingenuously used by those who would purposefully peddle mistruth – and focusing too much on the nuances and avoiding the simplicities can be dangerous when it comes time to make decisions with the information we have in hand. The author writes, in reference to disagreement amongst our legislators, that ".... Democrats on the committee printed off big piles of scientific papers that proved the very thing of which Smith had never seen evidence." (p.204). The epistemologist in me cries out at this, that "nothing is ever proved" – it would be safer to just state that there is overwhelming evidence and the burden of proof now falls on the other party. But most people are not epistemologists (and by the way "real" epistemologists would certainly not recognize me as one). We use the word "prove" in an everyday way, and since this book is targeted to an everyday audience, I must afford the author this consideration. At the end of the day, our world has real problems, and we have to take our best guess – not argue *ad nauseam* about how many angels can dance on the head of a pin. Still, I find the above problems to be present in this book, and I believe they are truly problems – at least in the context and for the reasons I have described.

In summary, I should finish where I began. I love this book. I have much in common with the author, not the least of which is that I earned a C in college biology in 1989 to match the author's C in organic chemistry in 1976, and it appears to have had the same effect on both of us – interpret that as you will. I am a professional scientist and spend my days studying the molecular biology of blood. Several years ago, I was wandering around the forest on Orcas Island with my daughter, who was 8 years old at the time. I was surrounded by a temperate forest of trees and moss– and yet, I felt entirely isolated from nature. Why would this be? It's because I personally experience nature using a mass spectrometer, a flow cytometer, and with next generation sequencing – in other words, I experience nature filtered through instruments, in abstract terms, and in a molecular/atomic world to which I have no direct access. I remember, at the time in that forest, how sad this felt to me – that my intellectual obsessions with nature were so far removed from the beauty in front of me. Don't get me wrong, I find as much beauty, elegance, and wonder in my scientific world as Dr. Rice finds in his – but then his world has special properties. They are not only what I can personally encounter, they are exactly what I evolved to encounter. They are the world and sensory input to which I belong. I now live in Virginia, surrounded by different flora and fauna but a very rich natural world. While walking my dog the other day (the one my daughter promised to take care of if we got it for her but never does), instead of obsessing over which amino acid on structural protein whatever was phosphorylated by kinase whichever, I saw the trees. I heard the sounds of the forest and smelled the fragrances of the woods. I happened to see the natural world in front of me – and not just as a work of art, but a work of scientific art, which is no less poetic. I attribute this reawakening of my appreciation of the forest to Dr. Rice's writings, and this is the very highest compliment I can pay him. As the spring begins to set in, I plan to measure the timing of the buds on different trees and plants as they wake up from their winter slumber, and I plan to record it – to see if it is changing in years to come. This is why we get into science to begin with, it is the intrinsic beauty and magic of the world, and this book conveys that in a wondrous way. The fact that I am performing these measurements to track the horrific effects of fossil fuel consumption, as we continue in our misguided and tragic quest to destroy the world my daughter will inherit, casts a dark shadow over the task. That those who would allow the world's destruction to protect their financial profit are spewing perverted pseudoscience to argue it isn't occurring, to perpetuate the wholesale destruction of our planet until it is too late, is also a message of this book – one we should not ignore. I would like to thank Dr. Stanley Rice for writing this work, for sharing it, and for tolerating my review of it.

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