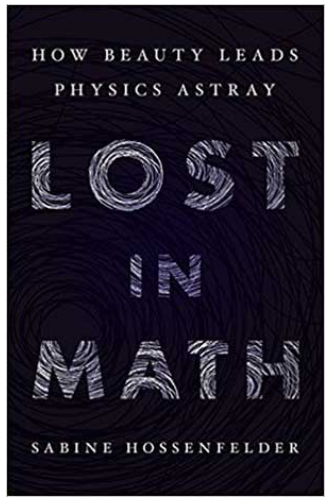
Book Review: Has Theoretical Physics Been Betrayed by Elegant Mathematics?

By Cormac O'Raifeartaigh

Review of Lost in Math: How Beauty Leads Physics Astray by Sabine Hossenfelder (Basic Books 2018)



Many readers will by now be aware of Sabine Hossenfelder's book '*Lost in Math: How Beauty Leads Physics Astray*.' A physicist well known to her peers for her work on quantum gravity and to the public for the widely-read blog 'Backreaction', Dr Hossenfelder has provided an unusual book that simultaneously presents a personal account of the challenges faced by early-career researchers in foundational fields such as particle physics, cosmology and quantum gravity, and a well-informed critique of the state of play of research in those fields today. Her main thesis is that the ever-widening gap between theory and experiment has created an unfortunate situation in which theoretical physics is being increasingly dominated by speculative theories that are being selected on the basis of aesthetic rather than scientific criteria.

Certainly, many physicists would agree that it is becoming ever more difficult (and expensive) to build experiments that can test our theories, in both the world of the very small and the world of the very large; where experiment once provided an important constraint, there is now a danger that theorists can become lost in a world of ever more complex mathematics disconnected from observation. This problem has been discussed at some length in the literature, notably in Lee Smolin's '*The Trouble With Physics*' and Peter Woit's '*Not Even Wrong*', but Hossenfelder's argument is at once more general and more pointed. Considering specific examples such as the theory of supersymmetry in particle physics, the many-worlds interpretation of quantum theory, the hypothesis of dark matter in astrophysics and the postulate of the multiverse in cosmology, she argues that the disconnect between theory and experiment has led to a situation where much of contemporary theoretical research is driven by

aesthetic considerations – i.e., that our 'best' theories are being selected on the basis of inappropriate and unscientific criteria such as elegance, symmetry and naturalness.

I found the book well-written, engaging, cogently argued and meticulously referenced, an absorbing read for anyone active in modern theoretical physics or with an interest in the field. I particularly enjoyed the way the narrative is interspersed with interviews conducted by the author with theorists such as Steven Weinberg, Frank Wilczek, Nima Arkani-Hamed and George Ellis, exposing the reader to reflections on the author's theme by leading figures in the field (although the stratagem did lead to a certain amount of repetition).

However, I was not ultimately convinced by the author's thesis. Time and again, I found myself wondering if the lack of progress in the examples cited is truly the result of an over-emphasis on mathematical elegance, or the result of a naturally-occurring hiatus in observation. After all, the history of physics is littered with examples where periods of hectic discovery were followed by periods of apparent stagnation; indeed, the latter are part and parcel of the practice of science. Certainly, it is striking how many of the interviewees stressed attributes such as elegance, naturalness and symmetry in theory development, but one wonders if there is a danger of taking such reflections too literally. I very much enjoyed Weinberg's observation that a racehorse breeder who declares a horse to be beautiful is not really referring to aesthetics, but attempting to articulate a tacit knowledge that the horse has many attributes that tends to win races.

To give a specific example, the author introduces the topic of supersymmetry (susy) by commenting; "*Besides revealing that fermions and bosons are two sides of the same coin, susy also aids the unification of fundamental forces and has the potential to explain several numerical coincidences ….it adds to susy's appeal that a symmetry relating bosons and fermions was long thought impossible because a mathematical proof seemed to forbid it*". This characterisation seems somewhat back-to-front and understates supersymmetry's role in unified field theory. (Following the spectacular success of electroweak theory, a number of powerful mathematical results from gauge theory indicated that it would not be possible to combine all four known interactions into a single, unified theory; a decade later, the theory of supersymmetry provided a crucial way around this devastating roadblock). Further discussions of the motivations for susy (such as the gauge hierarchy problem and coupling constant unification) are described later in the book but the author never truly explains the original motivation of the theory, ascribing its popularity instead to considerations of mathematical elegance. Thus, she attributes the statement by several interviewees that the supersymmetry "*must be true*" to an over-emphasis on the aesthetics of susy, whereas the statement probably reflects a reluctance by many to accept that only two of the known interactions can be unified in a single framework. It is interesting that the author takes the view that supersymmetry programme has been severely weakened by the fact that the simplest models now appear to be ruled out by

experiment; this stance, so prevalent amongst science writers and journalists, reflects an undue emphasis of the aesthetics of supersymmetry not shared by its original proponents.

More generally, I found the author's discussion of the role of symmetry considerations in theory development somewhat incomplete. The lay reader is given little hint that many physical processes emanate with a natural symmetry (due to a lack of preferred direction) and this is reflected in theoretical models for practical rather than aesthetic reasons. To be sure, the author gives a concise description of Murray Gell-Mann's use of symmetry groups to classify the elementary particles (a program that led to the discovery of quarks) and one has some sympathy for her view that "*just as experience with horses doesn't help when building a race car, experience with last century's theories might not be of much help conceiving better ones*". However, I was very surprised that no mention is made of Noether's theorem – the discovery of an astonishing correspondence between certain mathematical symmetries and conservation laws for certain physical quantities. This theorem has played a major role in modern particle physics and is a strong indicator of a deep connection between elegant mathematics and physics that is surely relevant to the author's thesis.

Turning to the sections on cosmology and astrophysics, I found the author's reflections on dark matter somewhat puzzling. The reader is presented with an exemplary description of the motivation for dark matter, and the current state of play of experimental searches for candidate particles such as WIMPS (weakly interacting massive particles). However, it is not made clear how the dark matter hypothesis reflects the central theme of an unhealthy obsession with beauty in theory development; indeed many would argue that our best models of dark matter reflect the hegemony of observation over elegant theory. Moreover, I found the author's suggestion that alternative explanations such as modified gravity fit the cosmological data less well than the standard model "*perhaps because fewer people are trying to make it fit*" a little back-to-front; most physicists would argue that fewer people work in such areas simply because the theories fit the data less well.

The discussion of dark energy left me similarly puzzled. Given that the phenomenon is represented in the standard concordance model of cosmology as an extra term in Einstein's field equations of gravitation - a variation of the theory not at all pleasing aesthetically – it is hardly an example of a preference for elegant theory over observation. I also found the author's statement that "*the belief that the value of the cosmological constant requires an explanation is an excuse for theoreticians to devise new laws of nature*" a little harsh. Given the well-known drastic mismatch between estimates of the quantum energy of the vacuum (the most obvious physical explanation for dark energy) and estimates from observation, it seems a reasonable topic for research. That said, a great many physicists will share the author's reservations concerning attempts by some theorists to explain the size of the dark energy component in terms of the multiverse. (Her discussion of the hypothesis of the multiverse in the context of string theory is equally pointed).

Finally, many researchers will find the author's list of strategies to avoid unconscious bias in theory development extremely useful. I also support her suggestion that physicists should seek the advice of philosophers in identifying and articulating the important questions of foundational physics today, although such interdisciplinary dialogues can be very difficult. All in all, a fascinating and thought-provoking read for anyone with an interest in modern theoretical physics.

Cormac O'Raifeartaigh lectures in physics at Waterford Institute of Technology and University College Dublin and is a Fellow of the Institute of Physics. He blogs at www.antimatter.ie.

The articles in this issue represent the views of their authors and are not necessarily those of the Forum or APS.