

## Naturalness in physics: just a matter of aesthetics?

Review of Sabine Hossenfelder, *Lost in Math: How Beauty Leads Physics Astray*, 2018, New York: Basic Books, 304 pages, \$30. Forthcoming in *Metascience*.

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Sabine Hossenfelder, a physicist by training, has made herself a name as a prolific blogger, criticizing recent developments in theoretical physics, such as the idea of the multiverse, supersymmetry, and string theory. She has also argued that the grounds for funding successors of the Large Hadron Collider (LHC) are weak. In her book *Lost in Math* she channels some of her criticisms. Her focus is on aesthetical motivations for developing successors to the standard model in particle physics, and in particular the curious property of ‘naturalness’.

Philosophers of science are well-aware of non-empirical properties of theories (e.g. simplicity and unification) can play a role in scientists’ theory choice. The ‘naturalness’ of theories, however, is not yet a property much discussed by philosophers of science as a general theory-choice criterion. Hossenfelder describes naturalness as the requirement that theories shouldn’t contain too large or too small numbers (14) or “ugly numerical coincidences” (ibid.). She also characterizes naturalness as the maxim that “what is unlikely to have occurred by chance should be avoided” (91). Violations of naturalness can indicate to scientists that deeper explanations are called for. The example repeatedly discussed by Hossenfelder is the mass of the Higgs boson, discovered at CERN in the LHC in 2012 with much attention from the media. The Higgs mass turned out to be relatively small, namely 125 GeV. The smallness of the Higgs mass is not a problem per se: the problem is generated by the fact that it ought to be much bigger, given its quantum interactions with all the other known particles (adding about 10<sup>14</sup> GeV). This can be fixed “by hand” by adjusting the so-called bare mass of the Higgs boson in such a way that the bare mass cancels out the massive contributions of the quantum corrections and leaves behind only the observed Higgs mass. This so-called fine-tuning seems very unlikely to happen just by chance. Physicists have therefore been looking for a more “natural” solution.

The best proposal physicists have been able to think of are supersymmetries, which postulate “superpartners” for the known particles. These superpartners (a “selectron” for the electron, “squarks” for quarks, etc.) would contribute opposite terms to the mass of the Higgs boson and thus cancel the effects of the masses of the known particles. If there were independent evidence for the superpartners of SUSY, we would have ourselves a good explanation of the Higgs mass. Unfortunately, the LHC hasn’t produced such evidence. What’s worse, the LHC hasn’t found any superpartners around the actual mass of the Higgs boson, which means that there will have to be fine-tuning to produce the Higgs mass after all, albeit at three orders of magnitude instead of about fifteen. Hossenfelder

argues that it this would be absurd, as the reason why SUSY was introduced in the first place was to avoid fine-tuning of the Higgs mass in the (38). Even if evidence for SUSY should be found eventually, naturalness seems to have been lost already, at least when understood as the complete absence of fine-tuning. Other important reasons to pursue SUSY, such as the unification of gauge couplings, Hossenfelder dismisses rather swiftly as just aesthetically pleasing and as not necessarily true (84).

Hossenfelder probes the concept of naturalness more fundamentally. What reasons do we have, she asks, to deem numerical properties of our models unlikely? Hossenfelder points out that we need to assume a certain probability distribution. For example, the probability of any of the six sides of a die to come up is random only provided that the die is regular. If the die is oddly shaped, this may no longer be the case. In physics, Hossenfelder argues, we have no reason to assume one or the other probability distribution for the parameters described by our theories. In particular, the distribution may be far from uniform. We therefore don't have a good foundation for thinking that the unnaturalness of a parameter like the Higgs mass is in need of explanation. In despair, Hossenfelder concludes: "I can't shake the impression that we're really trying to guess the rule God plays by, in order to make sure the laws of nature were chosen fairly [...]" (111).

Hossenfelder is convinced that all there is to naturalness is aesthetics: it is just a "feeling, not fact" (38). Interestingly, many of the physicists she interviewed for her book seem to agree with her that naturalness is a matter of aesthetics. And these are not just any physicists, but physicists of the stature of Steven Weinberg (who Hossenfelder herself considers the "greatest physicist alive"), Frank Wilczek, Gerard t' Hooft, Nima Arkani-Hamed, and others. Hossenfelder's frustration with the replies she gets to her piercing questions in these interviews is palpable. She believes that aesthetics simply shouldn't play a role in theory-choice in good science. The fact that it does seem to play such a role in physics Hossenfelder blames on detrimental sociological factors (153ff.) and biases (226ff). In that sense, her view is very similar to the ones advanced by Peter Woit and Lee Smolin in the case of String Theory (the latter of whom she credits for trying to "talk me out of writing this book").

I agree with Hossenfelder that if naturalness is just a matter of aesthetics, this would be problematic for the objectivity of physics. But is naturalness really just about aesthetics? Consider once more the example of the Higgs mass. What is problematic, it seems, is that there are no independent, theoretically motivated, reasons within the standard model for fixing the bare mass. The only reason for inserting such a big bare mass is the desire to accommodate the observed Higgs mass. In other words, the fine-tuning of the Higgs mass is ad hoc. This has little to do with aesthetics; it's just bad theorizing.

Although it's probably true that we will never have theories that do entirely without any ad hoc assumptions, good science tries to minimize them. As T.S. Kuhn and many other have pointed out, for example, many celestial phenomena that appeared to be coincidences to Ptolemaic astronomers, who tried to accommodate them by fiat, were later

shown to follow from the basic structure of the Copernican system. Similarly, whereas the equivalence of gravitational mass and inertial mass in Newtonian physics is entirely accidental, it follows from the geometry of spacetime in Einstein's general theory of relativity. All this constitutes progress in our understanding of the world. Hossenfelder knows herself that the facts alone are not enough to constrain theory choice: "Rather than falsifying theories, therefore, we "implausify" them: a continuously adapted theory becomes increasingly difficult and arcane—not to say ugly—and eventually practitioners lose interest" (40). Yet still one leaves with the impression that Hossenfelder believes that somehow physics would be helped if it just were to stick to the facts.

There is much to like about Hossenfelder's book. Hossenfelder is not only great at explaining difficult and abstract concepts and theories, but her writing is also highly entertaining. For example, expressing her frustration with the idea that the lack of evidence for supersymmetry at the LHC is interpreted by some as evidence for the multiverse, she says: "Theoretical physicists used to explain what was observed. Now they try to explain why they can't explain what was not observed." (108) During her visit of Steven Weinberg, she notes that his office is "half the size of mine, an observation that vaporizes what little ambition I ever had to win a Nobel Prize" (96). And with a good portion of self-irony, she remarks at one point: "Maybe I'm just here to find an excuse for leaving academia because I'm disillusioned, unable to stay motivated through all the null results [at the LHC]. And what an amazing excuse I have come up with—blaming a scientific community for misusing the scientific method" (81). Whether Hossenfelder's "excuse" is actually correct, remains to be seen. But what is clear, I think, is that Hossenfelder with this book (and in her other writings) has made a valuable contribution to methodological debates in physics and in science general. You may not agree with her, but Hossenfelder is forcing physicists to think harder about their own theory-choice criteria. It also invites philosophers of science to cast a more critical eye on what many still regard the model science. This can only be a good thing.

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