Should a Scientist Be Elegant?

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In a recent article, we argued that elegance is—or, better, should be—a central goal of scientific research (Nathan and Brancaccio, 2013). While researchers often praise the elegance and beauty of theories and experiments, elegance itself is usually treated as an accessory ornament and not a goal of science *per se*. Against this view, we suggested that elegance is an *intrinsic* feature of successful scientific practice, which should be actively pursued in our work. Just like other 'theoretical virtues'—such as *accuracy*, *generality*, and *testability*—elegance is a benchmark that demarcates good from bad science and, consequently, it should not be confined to grant proposals and coffee breaks; elegance belongs inside the lab. The goal of this essay is to elaborate and refine our conception of the role of elegance in science. We begin with a summary of our main proposal. Next, we clarify our position by addressing some objections that have been raised against our view, both in conversation and in writing.

1 Elegant Chapters from the History of Science

Despite the widespread recognition, admiration, and pursuit of elegance across several domains—such as art, literature, fashion, as well as science—two important questions are seldom addressed: *what* makes science elegant and *why* should science be elegant? Indeed, providing a general-yet-informative analysis of elegance has proven a daunting task. Nonetheless, the lack of a rigorous definition should not thwart a systematic analysis of the role of elegance in science, any more than the difficulty of characterizing *knowledge*, *justice*, and *probability* should undermine our engagement in meaningful conversations regarding epistemology, ethics, and statistics. The absence of precise definitions suggests a different strategy for understanding the role of elegance, that is, a critical review of paradigmatic case studies.

We discussed three episodes in the history of science that, in our opinion, instantiate well the ideal of elegance driving biomedical research: Jenner's discovery of *vaccination*, Bricker and Slatopolsky's *trade-off hypothesis*, and *Brenner's hypothesis* on the role of residual nephrons in the decline of renal function. The story of Jenner exemplifies an important dimension of scientific progress that is seldom discussed in textbooks. The discovery of a more effective (and less dangerous) alternative to variolation is a striking illustration of how a great sci-

entific discovery transcends a mere substantial improvement over a longstanding practice of immunization and epidemiological control. The integration of folk knowledge and technical expertise underlying vaccination provided an innovative *systematization* of various disconnected pieces of scientific knowledge, which opened up new and fruitful avenues for subsequent research. Such synthetic work, consisting in collecting superficially gerrymandered data and placing them together to form a coherent body of knowledge, is also evident in more recent episodes from the history of science. Bricker and Slatopolsky's trade-off hypothesis—the idea that organisms pay a biological 'price' in order to maintain the invariance of mineral metabolism (calcium and phosphate homeostasis)—reveals how elegance can manifest itself through a combination of simplicity and equilibrium, two theoretical 'virtues' that have been landmarks of elegance long before the 20^{th} century, especially in connection with the physical and mathematical sciences. The trade-off hypothesis was a simple idea, if ever there was one. Yet it required elegant minds to engineer an ingenious solution to design an experimental model that could then be effectively applied to clinical practice. Similarly, the elegance of Brenner's hypothesis regarding the role of residual nephrons in the decline of renal function lies in a combination of simplicity and linearity. Despite its remarkable essentiality, it is a unifying hypothesis that contributed to a deeper understanding and explanation of the possible mechanisms of progressive renal failure in non-immunological clinical conditions.

From a brief examination of these notable episodes, we concluded that elegance has an important role to play within scientific practice. What all the examples have in common is the willingness and capacity to break existing schemata. This audacity starkly contrasts with the repetitive employment of standard procedures, which is increasingly witnessed in the application of mathematical and statistical techniques to clinical research, such as meta-analysis. To be clear, our suggestion is *not* an outright rejection of statistical methodology, which has become a successful—indeed, irreplaceable—feature of contemporary scientific research. The point is rather that science only becomes truly innovative when the 'brute force' of mathematical frameworks is backed-up by some creative act of systematization. Elegant thinkers are able to move beyond conventional boundaries, shedding new light on old questions, and opening new avenues for research. In contrast, much current scientific work is focused on problems that have narrow scope, sometimes *too* narrow. Specialization is an inevitable feature of contemporary science. Nonetheless, even if brute force solutions are sometimes the easy route towards solving a problem, we should also pursue elegance in our work. In short, statistics is—and should continue to be—an important scientific tool; yet elegance, too, should leave the textbooks and hallways and make its way inside the laboratories.

2 Features of Elegant Science

In a brief response published as an appendix to our article, Dr. Meguid El Nahas (2013) has raised some concerns regarding our proposal, which he vividly ex-

pressed as follows: 'Elegance and Beauty are overwhelming and are on occasions at danger of overwhelming reality and true scientific facts' (p. 1389). Further elaborating on this point, El Nahas considers one of our examples—the Brenner hypothesis—that, as initially formulated 'with its elegance and beauty, very intuitive, very attractive, [and] therefore universally accepted without criticism' has been severely and, in his opinion, rightly criticized (p. 1389). The argument, however, is supposedly more general, bearing on a widespread tendency:

> Scientific endeavor whilst being enriched by intuition, lateral thinking and genial creativity is elegant by itself and beautiful by its process not by its outlook. ... I beg to differ as I would rather face factually correct science even though dry and difficult to digest to fanciful hypotheses that glide through the winds of elegance away from deeper scrutiny and criticism. ... I opt instead for a Popperian view of science based on the ugliness of falsifiability rather than the elegance of infaillability [*sic*] ... Falsifiability is the elegance of putting forward quests and hypotheses that are intrinsically challengeable and subsequently proved false ... discovery of truths through stepwise unravelling of falsehoods ... Perhaps, the Brenner hypothesis was both Elegant and False...!? (*ibidem*, 1398)

We would now like to discuss a few features of the argument that we find puzzling. Our goal is not to directly challenge Dr. El Nahas' perspective, which we appreciate and respect. Our aim is rather to address some confusions that are widespread within discussions of scientific methodology. Responding to his objections provides us with an opportunity to illustrate three characteristics that are central to our conception of elegant science.

First, it is crucial to distinguish between hypotheses that are *unfalsifiable* (that is, untestable, immune to empirical scrutiny) and hypotheses that are *false*. Early in the 20^{th} century, Popper (1935) famously maintained that falsifiability is the benchmark of science: any genuine scientific hypothesis must, at least in principle, be *testable*. Incidentally, we want to resist referring to this tenet as a 'Popperian' view of science, since Popper was neither original nor alone in emphasizing the centrality of testability in science, a position that was also explicitly advocated by his philosophical adversaries, the logical positivists (Schlick, 1933). Moreover, Popper's view of scientific methodology also encompassed a number of notorious claims—such as his radical skepticism towards all kinds of inductive inferences—which most contemporary scientists and philosophers rightly find unpalatable. Still, regardless of its label, the emphasis on testability is a sound methodological recommendation, which we unreservedly endorse. If *every* scientific hypothesis must be falsifiable then, *a fortiori*, no *elegant* scientific hypothesis can be unfalsifiable.

Falsity, in contrast, is a completely different story. Nothing prevents a hypothesis that is false (that is, disproved, shown to be inaccurate) from contributing to the elegance and progress of science. As an illustration, consider the so-called *central dogma of molecular biology*, according to which genetic

information within a biological system flows linearly from DNA to RNA to protein, and cannot be transferred back from protein to RNA to DNA (Crick, 1958). This principle, which once appeared unassailable, has now been challenged (Bussard, 2005). To be sure, a general assessment of the truth of the central dogma is a complex problem that transcends the scope of this work and the competence of the authors. Our point is much more straightforward. *Suppose*, for the sake of the argument, that the central dogma turned out to be false. Under these circumstances, would we be willing to deny its significance for the advancement of biological and biomedical and biomedical sciences in the 20^{th} century and, indeed, its elegance? Clearly not. The general moral that we ought to draw is that the falsity of a hypothesis is perfectly compatible with its significance, elegance, and fecundity—which, after all was one of Popper's important insights. Hence, El Nahas might well be right that Brenner's hypothesis is 'elegant but false' (a controversial statement that we shall not discuss here). If so, however, Brenner's hypothesis is not problematic *because* of its elegance; it is problematic *despite* its elegance.

This gets us to our third and final point. We recognize that elegance is often—all too often—employed to obscure serious methodological deficiencies in scientific work, such as shortcomings in the gathering of data or in experimental layout. However, this *extrinsic* notion of elegance is different, in important respects, from the *intrinsic* elegance that we advocate. Extrinsic elegance pertains to the presentation of evidence and results. Intrinsic elegance, in contrast, is part of the structure of the hypothesis itself. Thus, while a poor scientific argument can be disguised through an (extrinsically) elegant presentation, intrinsic elegant cannot be simulated or disguised: it is a fundamental components of the hypothesis and its relation to the data.

3 Scientific Methodology in the Grip of a False Dichotomy?

In the previous section, we discussed three important features of elegant science. First, the elegance of a hypothesis depends on its *intrinsic* structure and is thus independent on the mode of presentation. Second, like all of science, elegant science must be *falsifiable*, that is, subject to empirical scrutiny. Finally, a conjecture need not necessarily be *true* to be elegant, just as is subsequent rejection would not affect is contribution to the advancement of science. Indeed, even a false hypothesis may become a landmark of scientific progress and elegance.

We should also make it very clear that elegance, by itself, is not *sufficient* to make a good conjecture. A valuable scientific hypothesis must fulfil several 'virtues,' such as being testable, accurate, general, and perspicuous. This list—which does not purport to be complete—is not disjunctive either, in the sense that testability, by itself, does not warrant the scientific value of a hypothesis, unless said hypothesis is also accurate, general, perspicuous, etc. In our opinion, elegance deserves to be include among the theoretical virtues that characterize

good science. However, and this is the important point, the inclusion of elegance cannot replace or downplay other important features.

In conclusion, our plea for elegance is part of a broader critique of an overly narrow view of science. Much contemporary reflection on scientific methodology is driven by an idea of objectivity framed by a naïve hypothetico-deductive approach where scientific progress is reduced to bold conjectures confronting directly the tribunal of experience. Yet, contrasting the objectivity of 'hard facts speaking for themselves' with the alternative of a swampy relativism is unwarranted, as it presents us with a false dichotomy. Accepting that raw data is useless by itself, unless it is embedded within a richer experimental and theoretical context is tantamount to recognizing that science is a complex, nuanced, and fascinating endeavor that cannot be reduced to a handful of simplistic methodological norms. Now, surely, we are still far from a detailed and comprehensive analysis of the achievements, limits, and gradual progress of science. Yet, the failures to provide a clear model of scientific methodology should neither thwart future attempts not leads us to overlook the (partial) successes in understanding and elucidating the central features of the scientific and medical practice.

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