Beauty and Truth in the Natural Sciences

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1. Introduction

Of the immense mass of thoughts that have blossomed from human civilization, the scientific method is one of the most profound and far-reaching. Accumulating verifiable, precise knowledge and assembling them in a logically consistent framework, followers of science prove to be exceedingly adept in the march towards acquiring truth.[1] However, besides truth, many distinguished scientists share an obsession for beauty, an oddity in the strictly objective scientific world. What are the humane and logical elements underneath, and more fundamentally, what is the nature of this conjugate of truth and beauty? These questions form the core of this essay.

2. Truth

The notion of absolute truth, or external reality, should not be taken for granted in the natural sciences; for experimentation allies only with

1 In this essay, science is to be taken as a belief with its many assumptions; its powers are limited by its method, and its validity hinges on its basic assumptions. In short, science is falsifiable.

measurables derived from "reality", never reality itself.[2] Hence, rather than investigating reality; one defines truth as what is testified by experiments, and not deemed incorrect. Similarly, science needs not provide pictures of a phenomenon to satisfy the visually inclined mind; a model which utilizes mechanisms however outlandish is competent so long as its consequences are experimentally accurate and falsifiable.[3]

3. Beauty

Beauty[4] is a construct of human intellect with an emotional nature; a precise definition is therefore difficult to attain. Instead, the following sections highlight some generally accepted features of scientific beauty, all of which are, under deeper analysis, fundamentally intertwined.

3.1 Beauty as Simplicity

Upon discovering a plausible DNA model, James Watson expressed, "We felt sure that this was it. Anything that simple, that elegant just had to be right" (Watson 148). Undoubtedly, the pursuit of simplicity is a commandment of science. More than often, experimental science provides

2 It is a fact of experiment that different pieces of "truth" are self-consistent and accumulative; there is no "absolute truth" in this notion. Should nature prefer contradicting "truths", science may as well collapse.

3 i. Pictorial descriptions are often insufficient to enclose the entirety of the situation, such as a multi-dimensional space; for another reason, sometimes it is simply impossible to provide a pictorial description, such as in the "path" of a particle subject to the uncertainty principle; however, since the aim of science is just to provide accurate, verifiable accounts of nature, its inability in this respect renders no difficulty. ii. As an example, P.A.M. Dirac postulated the existence of an infinite sea of negatively charged particles filling all space to interpret positrons, or positively charged electrons, as holes in it. This yielded reasonable results, and is still true in solid state physics, its peculiar appearance notwithstanding.

4 In the following sections, beauty shall be synonymous with scientific beauty unless otherwise specified.

such abundance of details that the limited mind cannot wrestle with.[5] Therefore, the scientist starts his investigation of simple facts, facts he could handle and comprehend; if reality proves too complicated, he approximates or idealizes[6] to grasp the essence of the scenario. As history shows, for such methodology, the introduction of mathematization into analysis is inevitable.

3.2 Simplicity in the Form of Mathematization

Scientific experiments yield quantitative results; for discovering and expressing relations between quantities, mathematics, being remarkably compact and precise, is required. For instance, consider the data set generated by varying the voltage (V), current (I) and resistance (R) of a simple circuit; with a quick plot reveals a simple linear relation, given by the succinct equation: $V = IR$.[7] It is because of mathematization that we gain insight of the dependence of physical quantities, so that progress in asking the mechanisms behind this phenomenon is possible. With hindsight, mathematics exhibits a far more astonishing and powerful feature than simplification, and this is discussed in later sections.

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5 One may refer to Poincaré's views on simplicity, as in his *Science and Method*, I. The Selection of Facts, para. 1 and 8: "We cannot know all the facts, since they are practically infinite in number. We must make a selection [. . .] All that we can say is that we must prefer facts which appear simple, to those in which our rude vision detects dissimilar elements." See Henri Poincare, *The Value of Science: Essential Writings of Henri Poincare*. In *In Dialogue with Nature: Textbook for General Education Foundation Programme* (Hong Kong: Office of University General Education, 2011), 177, 179.

6 Approximation is the replacement of exact existences by inexact forms; idealization is the assumption that certain facts are completely false. Apparently similar, the two derive from entirely different methodologies.

7 As a digression, in physics one often employs a linear approximation, inserting higher-order correction terms at later stages. The principle of this practice is the same: a linear relation is most suggestive and simplest to manipulate.

3.3 Simplicity in Generality

The unification of all scientific knowledge, rooting far back in time, is the holy grail of science. Whereas mathematics derives consequences from axioms, scientific investigation tackles phenomena and minimizes the number of laws from which any possible event is factual if and only if it is a mathematical consequence.[8] Then we claim to understand, for mathematical logic and nature's laws are input parameters unique to this world, regardless of external intelligence.[9] We assume that the fundamental laws are general, mathematical and simple; that mathematical logic is irreducible and self-existent.[10]

As an illustration, special relativity—the jewel of modern physics—is based on merely two postulates: that the speed of light is invariant to any observer and the laws of physics are invariant to observers in uniform motion with each other. Together with the conservation laws of energy and momentum, one may derive new and bizarre results of energy-mass equivalence, time dilation while encompassing the entirety of Newtonian mechanics.[11] The symmetry thus displayed: the physical equivalence of all

8 This is expressed most succinctly by Einstein, “Everything should be made as simple as possible, but no simpler.”

9 As an extreme form of this belief, Sir Arthur Eddington, renowned for his work in general relativity and astrophysics, believed that the mass of the proton and electron are the only physical parameters required for a complete formulation of all physical theory.

10 The philosophical foundation of mathematics has always been subject to debate: Are numbers and the entirety of mathematics an external existence, as Gödel argued, or are they mere products of human intellect? However, in natural sciences one does not touch upon this subject; mathematical logic is assumed to be natural and fundamental. Whereas one may imagine mathematics to be completely different in a world without addition and multiplication, modern research in mathematics is trying to reduce the dependence of mathematics on our physical world as much as possible.

11 i. The rate of change of momentum is force. To be precise, the form of momentum needs to be revised for conservation to hold; but all the reader needs to know is that it can be accomplished. ii. The energy-mass relation is given, of course, by the most famous equation in the natural sciences: $E = mc^2$. iii. Roughly speaking, time dilation means that there is no “universal time”; time is observer-dependent.

corresponding frames suggests the lack of an absolute reference frame in nature.[12] This universal symmetry, an indiscrimination and uniformity of nature, is also observed in the cosmological principle[13] and the principles of variation and natural selection in the Darwinian evolution theory,[14] and is sought by the aesthetic soul.[15]

3.4 Simplicity as Understandability

The above list concerning scientific beauty is far from complete; precision, consistency, determinacy and purposefulness are but some unmentioned traits.[16] This matters not, for of utmost importance, encompassing simplicity and all other traits, is the question of origin: why does mankind consider these qualities beautiful?

My answer to this is simple: what is apparently comprehensible,

12 Symmetry is indisputably a form of beauty itself, and is inextricably linked with simplicity. There is a deep connection between symmetry and conservation laws in physics, and this connection is surprisingly general.

13 The cosmological principle states that observations from the Earth are in no way privileged to other frames; physical laws are universal and uniform. It is important to note that it is only a postulate. Also see Steven Weinberg, *The First Three Minutes*. In *In Dialogue with Nature: Textbook for General Education Foundation Programme* (Hong Kong: Office of University General Education, CUHK, 2011), 67.

14 The uniformity of the principles of variation and natural selection is apparent when compared to one of the prevailing ideas at the time, creationism based on Genesis. According to Darwin's principles, human beings are not preferred and unique spiritual "sons of God", but barely animals which had evolved into being no more different than other species according to the very same principles. This implication led to many attacks, both on Darwin himself and on his theory.

15 The beauty of symmetry is apparent in art, music and architecture; the rhyming of a poem, reflectional symmetry of Roman bridges and ternary (A-B-A) form in music are all subsets of this form of beauty.

16 Is the universe purposeful? This question has troubled some of the greatest philosophers of all time. For instance, in Newtonian physics we may describe the action of a particle as a consequence of the force imparted upon it. However, it can be mathematically proved that the same particle undergoes the path in which it minimizes a certain subsidiary of energy named the Lagrangian; so does the particle wish to attain minimum, or is it compelled into motion by an external agent, namely the force? As one may see, the notion of purposefulness is ambiguous.

we consider beautiful. An unnatural answer at first sight, note that the development of science is full of failed attempts; in this long process of trial-and-error, we discover that mathematics has the power to generalize known facts in accordance with mathematical logic without additional input, and yet the predicted results turn out to be experimentally correct.[17] Similarly, on our discovery hike scientific theories converge miraculously, and with more success grows our confidence.[18] Next, we try to apply what we find successful to alien situations, and continuously self-correct via experimentation and feedback. Certainly, as intelligent beings, we are not satisfied with only experimenting with the seemingly infinite elements presented to us, and instead we try to attribute a reason[19] to our success as we recognize certain patterns, in the hope that we can master a particular family of elements or phenomena once and for all. It is this simplicity, that one simple reason alone encompasses all such elements, that signifies our understanding of a certain field.

This is the familiar process of learning, and likewise the perception of beauty is greatly a learned experience; in turn, learning requires comprehension.[20] Simple facts, besides being more comprehensible, prove to be generalizable to tackle complexities.[21] Thus, upon confronting new

17 This is a very interesting point. Why should mathematics, which originated from simple empirics and human logic, be applicable to almost all branches of science? Is it an inborn ability that we can perceive the truth of nature? This question has been asked by none other than John von Neumann, Einstein and Poincaré.

18 There have been several great unifications of physics, starting from the unification of electricity and magnetism to the unification of three of the four basic forces known to mankind. This line of research, concerning grand unification theories, is lively with household names such as Einstein and Hawking indulging in it.

19 We understand when we have a successful reason. As for the definition of a reason, this is beyond my capability.

20 Beauty is, in a sense, a skill; it is greatly, if not purely, based on learning and experience, for it requires knowledge of the objects being judged.

21 That is to say, a greater truth may be assembled from partial truths.

situations where certain simplicities or symmetries are displayed, our intuition or experience drives us to consider them as more yielding and understandable than others. This forms the perception of scientific beauty, the ability to distinguish between the yielding and unyielding pieces of facts. As we go through the qualities of beauty, one indeed finds that such traits as consistency, determinacy, completeness, generality and purposefulness are all rooted to understandability either directly or via simplicity, and as for symmetry one recalls that it is regular patterns that we claim to understand, not the turmoil and disorder which confounds us. To quote from Newton, "Truth is ever to be found in simplicity, and not in the multiplicity and confusion of things." Indeed, in the eyes of many, truth is simple, non-confusing and equivalently understandable.[22] Thus, the quest for beauty is essentially a quest for simplicity and understandability as displayed in truth.

4. Truth and Beauty

Logical science—rigorous and lifeless by nature, is not suited to the inborn nature of man; a man may express his findings in a perfectly logical manner, but one must rely on intuition for discovery. The beliefs in science listed above—the traits of beautiful truth and understandability—may be considered as hypotheses derived from a great experiment itself: if they turn out to be false, the "theory of truth" should be altered to aid the discovery of

22 i.Which comes to the greatest mystery in science, as in the words of Einstein: "The most incomprehensible thing about the universe is that it is all comprehensible." As we now know, comprehensibility is by itself not absolute; the uncertainty principle in quantum mechanics provides the most radical counter-example. Basically speaking, it means that the same experiment, carried under perfectly identical conditions, need not yield identical results, and it is impossible to predict the exact results; one can only give a statistical account for that. Thus the end of our deterministic beliefs. ii. A deeper thought confirms that consistency, purposefulness and determinacy as traits of understandability; we "understand" logic and definite forms, but not random variations.

truth.[23] In order to substantiate this view, let us consider two questions: first, is truth necessarily beautiful? And second, is a beautiful object necessarily true?

The first question is easy to address. For all its prowess and feats, physics has failed to account for the phenomenon of turbulence, or the irregular flow of fluid, for example, in rising smoke. We can, in principle, obtain the laws for the intermolecular forces, neglect other effects,[24] and compute the forces between each particle; but what a tremendous task it will be, with the astronomical number of particles! If we consider other effects and also the interaction thus created, the theory will then be frustratingly complicated and chaotic,[25] not to mention beautiful.[26] Henceforth, truth is not intrinsically beautiful.

The second question is of much deeper nature, and calls for division into two cases: one, that the sense of beauty is solely a learned experience, and two, otherwise. The first case requires a further sub-division: either nature may be reduced to finite sub-groups, or nature is infinitely variant.[27] If the latter holds, developing a perfect sense of beauty by sheer experience

23 Always assuming, of course, that the theory is by itself consistent and comprehensible. Nature is assumed to be merciful to intelligent, inquisitive beings.

24 As customary, the negligence of other effects is to simplify the problem; one needs to worry of fine corrections only when the major effect is understood.

25 Chaos, as understood as chaos theory, is also a lively field in physics bearing a fair resemblance to turbulence. Here, however, it is to be understood in daily terms.

26 There is scarcely any symmetry in this problem, and it is an application of existent knowledge without providing new insights; it is not general, and nowhere near simple. Apparently, complexity is a definite form of anti-beauty, and I would consider this criterion as universal.

27 By a sub-group or variation I mean phenomenon which may be classified as having similar mechanism, or with a theory in which the mathematics adopted is similar. For example, a spring-mass system is similar to an capacitance-inductance circuit in terms of the mathematical formulation; and waves of all kinds are similar in the sense that the mechanism behind is similar. Since this extent of grouping is ambiguous, let me define a new variation as follows: a new variation if what requires new forms of mathematical formulations, or is unexplainable by use of consistent pieces of known truths.

is impossible. If not, such development is possible but highly improbable, given strikingly incalculable known variations and continued discovery of new variations. In either case, a beautiful object, as defined by our sense of beauty, is not necessarily true.[28]

Thus, greater interest lies in the second case: that the sense of beauty is not a solely learned experience, and the human mind is able to, without any background knowledge in a certain field, simulate truth.[29] But wild guesses may also yield truth by chance; what is important is the possibility of strict implication of mathematical truth by beauty.[30] Modern mathematics seems to probe deeper than physical reality itself, creating all kinds of models suitable for worlds with different sets of fundamental laws.[31] Hence, rather than saying that mathematics and physical reality are in one-to-one correspondence, it is more appropriate to say that our physical world is just a sub-world of the mathematical worlds which has miraculously propagated from human intelligence and this physical world alone. In this sense, mathematical beauty does not strictly imply truth—it is even more than that. As for the portion of

28 That is, it is impossible to develop a perfect sense of beauty.

29 Should mathematics turn out to be at least partially a human construct, or an invention instead of a discovery, then this assumption is trivially satisfied. To generalize the problem, do humans merely learn and mimic, or are they capable of pure creation? The answer to this question, if attainable, leads to very interesting consequences.

30 P.A.M. Dirac (1902–1984), a brilliant theoretical physicist and Nobel-prize laureate at 31, was a fanatic of beauty: at one point, he considered having beauty in equations is more important than fitting it with experiments. This is a extreme case in which the pursuit of beauty exceeds the original pursuit of experimental truth. He goes on further to describe his thoughts on understanding: "I consider that I understand an equation when I can predict the properties of its solutions, without actually solving it." Undoubtedly, his skills in the perception of beauty were outstanding, but this did not prevent him from suffering from his relatively fruitless scientific career in his later life.

31 For example, infinite-dimensional space and Riemannian geometry assumes forms which, at their time of discovery, have no counterpart in the natural sciences. We now know that general relativity adopts the use of Riemannian geometry, while various-dimensional space is used in various unification theories.

mathematics that relates to reality, with all mathematical aptitude known to mankind, a humanistic selection must incur for a mathematically beautiful object to transform into a physical truth, and thereby create imperfection.[32] Thus, not only are mathematically beautiful objects not necessarily true, but also such objects selected by the most skilled humans to fit into a physical picture are not necessarily true. Beauty is beauty, and truth truth; this is the truth that is presented to us.

5. Conclusion

John Keats once wrote:

> "Beauty is truth, truth beauty,"—that is all
> Ye know on earth, and all ye need to know.[33]

We may never interpret Keats' thoughts as expressed in this line, for poets do not write to be understood. The thesis establishes a humane beauty, as opposed to definite, rigorous truth, and assigns understandability to all forms of beauty, with generality and mathematization being derivatives of the sub-character of simplicity. Beauty and truth are, by nature, non-identical, but the ability to perceive beauty and fathom beauty in truth is a skill important and necessary for discovery. Whereas this perfect skill is hardly attainable, besides a complete mathematical description, it is a goal of science to provide

32 The human sense is not a definite measure; it is affected by emotion, physical circumstances and other factors. Thus, human intervention is a source of imperfection. This point is controversial; however, one may interpret this as the probability of human intervention convergent with perfection is small.

33 John Keats (1795–1821) was a renowned English Romantic Poet. These lines are extracted from his *Ode on a Grecian Urn*, lines 49–50. See "Ode on a Grecian Urn" in *Wikipedia* (Retrieved 15:14, Dec 6, 2011).

it as a "common sense" to truth, such that even a commoner can feel ultimate scientific truth; until then shall beauty and truth be truly unified, and shall we claim that we, as intelligent beings, are truly and honestly in dialogue with nature.

Works Cited

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Teachers' comment:

This essay shows a very good integration among the UGFN texts and the author's knowledge. The structure of the essay is absolutely clear. The introduction presents to the reader a whole picture of the essay and also the core questions. This will certainly help prepare the reader's mind and draw his attention to the main theme. The main body starts with a search of the meaning of truth, which is followed by a discussion of what is meant by beauty. The attempt to dissect the relation between truth and beauty is enlightening and smoothly leads to the conclusion.

The arguments are also very well-structured. Support by texts and literatures adds to their convincing power. This essay shows the author's deep reflection and good understanding of the method of science, which is demonstrated by the relevant examples from physical sciences. The author's awareness of possible weaknesses in arguments, as reflected by the qualifications and supplementary information in the footnotes, is appreciated. (Chan Chi Wang, Szeto Wai Man, Wong Wing Hung)