Quotations on simplicity, falsifiability, the general modelling nature of mathematics, and mathematical beauty

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1 Simplicity, of models and of nature

1.1 Ernst Schmutzer, 1968
Relativistische Physik (Klassische Theorie)

> Die relativistische Theorie ist ein Musterbeispiel für das Leitprinzip, nach dem Naturgesetze gebaut zu sein scheinen: "So einfach wie möglich, so kompliziert wie nötig"

> Relativity theory is a prime example of the leading principle according to which seem to be built the laws of nature: "As simple as possible, as complex as necessary"

1.2 Hideki Yukawa, 1959 < 湯川 秀樹
Inscribed with chalk on the walls of Prof. Dmitro D. Ivanenko's office at Moscow State University, 28 Jul 1959
(http://gnsardan.appfarm.ru/nobel2.html)

> 自然は本質において簡単である (佐藤 文隆)

> Nature is simple in its essence (Humitaka Sato)

1.3 Roger Sessions, 1950
How a 'difficult' composer gets that way
New York Times, 8 Jan 1950, p. 89

> I also remember a remark of Albert Einstein, which certainly applies to music. He said, in effect, that everything should be as simple as it can be, but not simpler!

Note: For the follow-up variations see http://quoteinvestigator.com/2011/05/13/einstein-simple/

1.4 Albert Einstein, 1933
On the method of theoretical physics
The Herbert Spencer Lecture, delivered at Oxford (10 Jun 1933)
= *Philosophy of Science*, vol. 1, no. 2 (Apr 1934), p. 163–169 → 165

> The supreme goal of all theory is to make the irreducible basic elements as simple and as few as possible without having to surrender the adequate representation of a single datum of experience.

1.5 Ludwig Wittgenstein, 1921
Logisch-Philosophische Abhandlung, 6.363
Annalen der Naturphilosophie, vol. 14, p. 184–262 → 259

> Der Vorgang der Induktion besteht darin, dass wir das *einfachste* Gesetz annehmen, das mit unseren Erfahrungen in Einklang zu bringen ist.

> *Tractatus Logico-Philosophicus* (London: Routledge & Kegan Paul 1922), p. 178–181

> > The procedure of induction consists in accepting as true the *simplest* law that can be reconciled with our experiences.

1.6 Alfred North Whitehead, 1919
The Concept of Nature
The Tarner Lectures, delivered in Trinity College (Nov 1919), ch. VII, p. 163

> The aim of science is to seek the simplest explanations of complex facts. We are apt to fall into the error of thinking that the facts are simple because simplicity is the goal of our quest. The guiding motto in the life of every natural philosopher should be, Seek simplicity and distrust it.

1.7 David Hilbert, 1900
Mathematische Probleme
Lecture before the International Congress of Mathematicians, Paris, 8 Aug 1900
Nachrichten der Königlichen Gesellschaft der Wissenschaften zu Göttingen. Mathematisch-physikalische Klasse, 1900, p. 253–297 → 257

= *Archiv der Mathematik und Physik*, ser. 3, vol. 1 (1901), p. 44–63, 213–237 → 48

> Die strenge Methode auch zugleich die einfachere und leichter faßliche ist. Das Streben nach Strenge zwingt uns eben zur Auffindung einfacherer Schlußweisen; auch bahnt es uns häufig den Weg zu Methoden, die entwickelungsfähiger sind als die alten Methoden von geringerer Strenge.

> Mathematical problems
Bulletin of the Americal Mathematical Society, vol. 8 (1902), p. 437–479 → 441

> > The rigorous method is at the same time the simpler and the more easily comprehended. The very effort for rigor forces us to find out simpler methods of proof. It also frequently leads the way to methods which are more capable of development than the old methods of less rigor.

1.8a Ernst Mach, 1883
Die Mechanik in ihrer Entwickelung historisch-kritisch dargestellt, cap. 4, § 4.6

> Die Wissenschaft kann daher selbst als eine Minimumaufgabe angesehen werden, welche darin besteht, möglichst vollständig die Thatsachen mit dem *geringsten Gedankenaufwand* darzustellen.

> > Science itself, therefore, may be regarded as a minimal problem, consisting of the completest possible presentment of facts with the *least possible expenditure of thought*.

1.8b Idem, 1882
Über die ökonomische Natur der physikalischen Forschung (Wien: Gerold)
(http://euster42.dyndns.org/mauthner/hist/mach2.html)

> Den sparsamsten, einfachsten begrifflichen Ausdruck der Tatsachen erkennt sie [Naturwissenschaft] als ihr Ziel.

> The goal which [natural science] has set itself is the simplest and most economical abstract expression of facts.

1.9a William Hamilton, 1853
Discussions on Philosophy and Literature, Education and University Reform, ap. I (A), p. 628 of 2nd enlarged ed. printed in London by Longman.

> *The Law of Parcimony* (as the rule ought to be distinctively called) [...]: *Neither* more, *nor* more onerous, *causes are to be assumed, than are necessary to account for the phænomena*.

1.9b Idem, 1836–37
Lectures on Metaphysics, lect. XXXIX, XL
= *Lectures on Metaphysics and Logic* (ed. H.L. Mansel and J. Veitch, 1859–60), vol. 1, p. 546, 556
(http://archive.org/stream/lecturesonmetap00hamigoog)

> This is the law of Parcimony, which forbids, without necessity, the multiplication of entities, powers, principles, or causes; above all, the postulation of an unknown force, where a known impotence can account for the effect. We are, therefore, entitled to apply Occam's razor to this theory of causality.
>
> [...]
>
> Nature never works by more and more complex instruments than are necessary; — μηδὲν περιττῶς; and to assume a particular force, to perform what can be better explained by a general imbecility, is contrary to every rule of philosophizing.

1.10 Isaac Newton, 1687–1726
Philosophiae Naturalis Principia Mathematica, lib. III
(ed. A. Koyré, I. B. Cohen, Cambridge 1972, vol. II, p. 550–551)

> {Regula I [Philosophandi].}[1] *Causas rerum naturalium non plures admitti debere, quam quae et vera sint et earum phaenomenis explicandis sufficiant*. {Dicunt utique philosophi: Natura nihil agit frustra, et frustra fit per plura quod fieri potest per pauciora.}[2] Natura enim simplex est et rerum causis superfluis non luxuriat.
>
> [1] Hypothesis I *in 1st ed.* [2] *Not present in 1st ed.*

> Rule I [of Reasoning in Philosophy] *There should not be admitted more causes of natural things than are both true and sufficient to explain their phenomena*. As the philosophers say, Nature does nothing in vain, and more causes are in vain when fewer suffice. For nature is simple and does not indulge in the luxury of superfluous causes.

1.11 Gottfried Wilhelm Leibniz, 1670
Dissertatio de Stilo Philosophico Nizolii, §28
(Opera Philosophica, vol. I, ed. J. E. Erdmann, Berlin 1840, p. 55–71 → 69a)

Hypothesin eo esse meliorem, quo simpliciorem.

> The simpler a hypothesis is, the better it is.

1.12 Pierre de Fermat, 1662
[*Synthesis ad refractiones*]
(Oeuvres, vol. I, ed. P. Tannery & Ch. Henry, 1891, p. 173)

Naturam operari per modos et vias faciliores et expeditiores.

> Nature operates by the simplest and most expeditious ways and means.

1.13a Johannes Kepler, 1618
Epitome Astronomiae Copernicanae, lib. I, pars V, §1.1
(Gesammelte Werke, vol. VII, ed. M. Caspar, 1953, p. 80)

Natura semper quod potest per faciliora, non aget per ambages difficiles.

> Nature never does by difficult windings what can be done in easier ways.

1.13b Idem, 1596
Mysterium Cosmographicum, cap. I
(Gesammelte Werke, vol. I, ed. M. Caspar, 1938, p. 16)

Amat illa [Natura] simplicitatem, amat vnitatem. Nunquam in ipsa quicquam ociosum aut superfluum extitit; at saepiùs vna res multis ab illa destinatur effectibus.

> Nature likes simplicity and unity. Nothing trifling or superfluous has ever existed: and very often, one single cause is destined by itself to [produce] several effects.

1.14a John Duns Scotus, *ca* 1295
Quaestiones in octo libros Physicorum Aristotelis, I 8
(Opera Omnia. Editio nova, vol. II, Paris 1891, p. 395b)

Frustra fit per plura, quod potest fieri per pauciora.

> It is futile to do with more things that which can be done with fewer.

1.14b Idem, *ca* 1295
Quaestiones super libros Metaphysicorum Aristotelis, I 4.41
(Opera Philosophica, vol. III, ed. R. Andrews *&* *al*, New York 1997)

Numquam est ponenda pluralitas sine necessitate.

> Pluralities ought not be posited without necessity.

Note: Both these statements of John Duns are often attributed to William of Occam, who gives the same wordings but in latter dates.[1] The term "Occam's razor" was introduced by William Hamilton in 1.9b.

[1] See William M. Thorburn 1918 · The myth of Occam's razor · *Mind*, vol. 27, no. 107, p. 345–353 = http://en.wikisource.org/wiki/The_Myth_of_Occam's_Razor.

1.15 Thomas de Aquino, 1256–1259
Quaestiones disputatae de Veritate, q. 12 a. 2 arg. 3
(http://www.corpusthomisticum.org/qdv12.html)

Natura non abundat superfluis, nec deficit in necessariis.

> Nature does not provide superfluities nor fail in necessary matters.

1.16 Maimonides, *ca* 1190 < רבי משה בן מימון
The Guide for the Perplexed, lib. II, cap. XI < דלאלה אלחאירין, אלגו אלתאני, פצל יא
(Le Guide des Égarés, vol. II, ed. S. Munk, Paris 1861, with judeo-arabic text and french translation, http://books.google.es/books?id=51w_AAAAYAAJ)

> He will [the astronomer], besides, endeavour to find such an hypothesis which would require the least complicated motion and the least number of spheres.

1.17 Averroes, ∗ 1126 / †1198 < أبو الوليد محمد بن أحمد بن محمد بن أحمد بن رشد
Commentarium Magnum in Aristotelis Physicorum, 50
(http://dare.uni-koeln.de/?q=node/32)

> Cum concesserimus, quod natura potest facere ex principiis finitis illud, quod facit ex infinitis, melius est et rectius, ut faciat hoc ex finitis, et si non, tunc natura ageret otiose. Qui enim potest sanare modica actione, ille agit actione artificiali. Si autem laboraverit actione maiori, otiose faciet et superflue. Et ita est de natura, sicut de arte.

> Since we admit that nature can do from a finite number of principles what it does from an infinite number of them, it is better and more correct that it does it from a finite number of them; if not, then nature would act in vain. Indeed, who can make things better by means of a moderate action acts artfully. If, otherwise, he works with a greater action, he will make it in vain and superfluously. And so is it with nature as well as art.

Note: Thorburn 1918 (cited in 1.13) refers to Averroes as the possible source of the statement "Natura non agit per plura, quod fieri per pauciora potest". However, the reference he gives leads to the preceding quotation.

1.18a Aristotle, *ca* 335/323 b.C. < Ἀριστοτέλης
Physica, I 4, 188 a 17–18 < Φυσικῆς ἀκροάσεως
(http://www.kennydominican.joyeurs.com/GreekClassics/AristotlePhysics.htm)

βέλτιόν τε ἐλάττω καὶ πεπερασμένα λαβεῖν, ὅπερ ποιεῖ Ἐμπεδοκλῆς.

> Praestat autem pauciora et finita [principia] sumere; quod quidem facit Empedocles.

> And it is better to assume a smaller and finite number [of principles], as Empedocles does.

1.18b Idem
De Caelo, I 4, 271 a 33 < Περὶ οὐρανοῦ
(http://www.kennydominican.joyeurs.com/GreekClassics/AristotleHeavens.htm)

ὁ δὲ θεὸς καὶ ἡ φύσις οὐδὲν μάτην ποιοῦσιν.

> At Deus, et natura, nihil prorsus faciunt frustra.

> But God and nature create nothing that is pointless.

1.18c Idem

De Anima, III 12, 434 a 31 < Περὶ Ψυχῆς

(http://www.kennydominican.joyeurs.com/GreekClassics/AristotleSoul.htm)

μηθὲν μάτην ποιεῖ ἡ φύσις.

> Nihil facit frustra natura.

> Nature does nothing in vain.

1.18d Idem

Politica, I 2, 1253 a 9 < Πολιτικά

(http://www.kennydominican.joyeurs.com/GreekClassics/AristotlePolitics.htm)

οὐθὲν γάρ, ὡς φαμέν, μάτην ἡ φύσις ποιεῖ.

> Nihil enim frustra facit natura, ut dicimus.

> Nature, as we often say, makes nothing in vain.

2 Inexactness of models and falsifiability of empirical science

2.1 George E. P. Box, 1978
Robustness in the strategy of scientific model building
Robustness in Statistics
(Proceedings of a workshop held on 11–12 April 1978; ed. R. L. Launer & G. N. Wilkinson; New York: Academic Press 1979)

All models are wrong, but some are useful.

2.2 Georg Rasch, 1960
Probabilistic Models for Some Intelligence and Attainment Tests, p. 37–38

Models should not be true, but it is important that they are applicable.

[It may be objected that this model cannot be true. That the model is not true is certainly correct, no models are —not even the Newtonian laws. When you construct a model you leave out all the details which you, with the knowledge at your disposal, consider inessential —like in the pendulum model described in ch. I. Models should not be true, but *it is important that they are applicable*, and whether they are applicable for any given purpose must of course be investigated. This also means that a model is never accepted finally, [but] only on trial. In the case which we discuss, we may tentatively accept the model described, investigate how far our data agree with it, and perhaps find discrepancies which may lead us to certain revisions of the model.]

2.3 Karl R. Popper, 1934
Logik der Forschung, p. 15

Ein empirisch-wissenschaftliches System muss an der Erfahrung scheitern können.

> *The Logic of Scientific Discovery* (London: Hutchinson 1959)

> It must be possible for an empirical scientific system to be refuted by experience.

2.4 Albert Einstein, 1921
Geometrie und Erfahrung, p. 3–4

Insofern sich die Sätze der Mathematik auf die Wirklichkeit beziehen, sind sie nicht sicher, und insofern sie sicher sind, beziehen sie nicht auf die Wirklichkeit.

> Geometry and Experience
Sidelights on Relativity (London: Methuen 1922), p. 28

> As far as the laws of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality.

2.5 August Weismann, 1868
Über die Berechtigung der Darwin'schen Theorie, p. 14

Lässt sich eine wissenschaftliche Hypothese zwar niemals erweisen, wohl aber, wenn sie falsch ist, widerlegen.

> A scientific hypothesis can never be proven, but it can certainly be refuted when it is false.

2.6a Christian Doppler, 1852

Bemerkungen über die von dem Herrn Prof. Petzval gegen die Richtigkeit meiner Theorie vorgebrachten Einwendungen.

Sitzungsberichte der kaiserlichen Akademie der Wissenschaften. Mathematisch-naturwissenschaftliche Classe, vol. 9, p. 217–225 → 220

> Hunderte von Erfahrungen einer Hypothese erst zu einiger Wahrscheinlichkeit verhelfen können, während eine einzige gegentheilige sie ganz und gar zu vernichten im Stande ist.

> Hundreds of experiences of a hypothesis can only help to some degree of probability, while a single opposite is able to completely destroy it.

2.6b Idem, 1844

Ueber die bisherigen Erklärungsversuche des Aberrations-Phänomens.

Abhandlungen der königlichen böhmischen Gesellschaft der Wissenschaften, ser. 5, vol. 3, p. 747–765 → §16

> Wenn eine Hypothese selbst eine noch so grosse Anzahl der komplicirtesten Naturerscheinungen, für die sie gelten soll, ganz genügend erklärt, mit einer einzigen Erscheinung derselben Art aber in einem offenbaren Widerspruche steht, oder zum wenigsten sie überhaupt nicht erklärt: so ist dies ein ganz unleugbares Kennzeichen davon, dass diese Hypothese im ganzen genommen nicht die wahre und richtige sein könne.

> Even though a hypothesis explains quite satisfactorily a large number of the most complex natural phenomena to which should apply, if it stands in open contradiction to a single phenomenon of the same kind, or at least it does not explain it at all, then this is a very undeniable indicator that this hypothesis, taken as a whole, could not be true and correct.

3 The general modelling nature of mathematics

3.1 Exhibition on Mathematical Modelling. Univ. Autònoma de Barcelona, Dep. Matemàtiques & Biblioteca de Ciència i Tecnologia, Feb 2011

Les àrees més bàsiques de les matemàtiques es poden veure com a models d'aspectes molt generals de la percepció humana de la natura. Així, podem dir que:

- La lògica matemàtica modela el raonament.
- Els nombres naturals modelen la noció que sorgeix de comptar objectes.
- La geometria modela l'espai.
- Els nombres reals modelen la mesura de magnituds.
- La teoria de probabilitat modela l'aleatorietat.

Els axiomes de cadascuna d'aquestes teories, que han estat aïllats curosament amb el temps, des d'Euclides a Kolmogorov, juquen un paper anàleg a, per exemple, les lleis fonamentals de la física.

> The most basic areas of mathematics can be seen as models of very general aspects of the human perception of nature. So, we can say that:

- Mathematical logic models reasoning.
- The natural numbers model the notion that arises from counting objects.
- Geometry models space.
- The real numbers model the measurement of magnitudes.
- Probability theory models chances.

The axioms of each of these theories, which have been carefully isolated through time, from Euclid to Kolmogorov, play an analogous role to, for instance, the fundamental laws of physics.

3.2 Vladimir Igorevich Arnol'd, 1997 < Владимир Игоревич Арнольд

О преподавании математики

Address at a discussion on teaching of mathematics in the Palais de la Découverte, Paris, 7 Mar 1997

Успехи Математических Наук, vol. 53 (1998), no. 1, p. 229–234 → 229

Математика — часть физики. Физика — экспериментальная, естественная наука, часть естествознания. Математика — это та часть физики, в которой эксперименты дёшевы.

> On teaching mathematics

Russian Mathematical Surveys, vol. 53 (1998), no. 1, p. 229–235 → 229

> Mathematics is a part of physics. Physics is an experimental science, a part of natural science. Mathematics is the part of physics where experiments are cheap.

3.3 Albert Einstein, 1921
Geometrie und Erfahrung, p. 6

> Die so ergänzte Geometrie ist offenbar eine Naturwissenschaft; wir können sie geradezu als den ältesten Zweig der Physik betrachten. Ihre Aussagen beruhen im wesentlichen auf Induktion aus der Erfahrung, nicht aber nur auf logischen Schlüssen.

> Geometry and Experience
Sidelights on Relativity (London: Methuen 1922), p. 28, 31, 32

> > Geometry thus completed is evidently a natural science; we may in fact regard it as the most ancient branch of physics. Its affirmations rest essentially on induction from experience, but not on logical inferences only.

3.4 David Hilbert, 1900
Mathematische Probleme
Lecture before the International Congress of Mathematicians, Paris, 8 Aug 1900
Nachrichten der Königlichen Gesellschaft der Wissenschaften zu Göttingen. Mathematisch-physikalische Klasse, 1900, p. 253–297 → 256

= *Archiv der Mathematik und Physik*, ser. 3, vol. 1 (1901), p. 44–63, 213–237 → 47

> Sicherlich stammen die ersten und ältesten Probleme in jedem mathematischen Wissenszweige aus der Erfahrung und sind durch die Welt der äußeren Erscheinungen angeregt worden. Selbst die Regeln des *Rechnens mit ganzen Zahlen* sind auf einer niederen Kulturstufe der Menschheit wohl in dieser Weise entdeckt worden, wie ja auch heute noch das Kind die Anwendung dieser Gesetze nach der empirischen Methode erlernt.

> Mathematical problems
Bulletin of the Americal Mathematical Society, vol. 8 (1902), p. 437–479 → 440

> > Surely the first and oldest problems in every branch of mathematics spring from experience and are suggested by the world of external phenomena. Even the rules of *calculation with integers* must have been discovered in this fashion in a lower stage of human civilization, just as the child of to-day learns the application of these laws by empirical methods.

3.5 Friedrich Engels, 1877
Herrn Eugen Dühring's Umwälzung der Wissenschaft. 1. Philosophie

> Keineswegs aber befaßt sich in der reinen Mathematik der Verstand bloß mit seinen eignen Schöpfungen und Imaginationen. Die Begriffe von Zahl und Figur sind nirgends anders hergenommen, als aus der wirklichen Welt.

> > But it is not at all true that in pure mathematics the mind deals only with its own creations and imaginations. The concepts of number and form have not been derived from any source other than the world of reality.

3.6 Hermann von Helmholtz, 1870
Über den Ursprung und die Bedeutung der geometrischen Axiome
Lecture delivered in the Teaching Union, Heidelberg, 1870
Populäre Wissenschaftliche Vorträge, 2d ed. (Braunschweig: Vieweg 1876), vol. 3, p. 21–51 → 49

Die geometrischen Axiome sprechen also gar nicht über Verhältnisse des Raumes allein, sondern gleichzeitig auch über das mechanische Verhalten unserer festesten Körper bei Bewegungen.

> Thus the axioms of geometry do not speak about properties of space alone, but also about the mechanical behaviour of our most rigid bodies when they are in motion.

3.7 George Boole, 1854
An investigation of the Laws of Thought, on which are founded the mathematical theories of logic and probabilities, § I.1

The design of the following treatise is to investigate the fundamental laws of those operations of the mind by which reasoning is performed.

3.8 Carl Friedrich Gauss, 1817
Letter to Heinrich W. M. Olbers, Göttingen, 28 April 1817
Werke, vol. 8, p. 177

Bis dahin müsste man die Geometrie nicht mit der Arithmetik, die rein a priori steht, sondern etwa mit der Mechanik in gleichen Rang setzen.

> Until then, we should not put geometry on the same rank with arithmetic, which stands purely *a priori*, but say with mechanics.

4 Mathematical beauty

4.1a Paul Adrien Maurice Dirac, 1970
Can equations of motion be used in high-energy physics?
Physics Today, Apr 1970, p. 29–31

> A theory with mathematical beauty is more likely to be correct than an ugly one that fits some experimental data.

4.1b Idem, 1968/69
Conversation with Jagdish Mehra in Trieste, June 1968, and in Miami, 28 March 1969
Aspects of Quantum Theory (ed. A. Salam & E. P. Wigner, Cambridge Univ. Press 1972), p. 17–59 → 59, note 78

> If the equations of physics are not mathematically beautiful, that denotes an imperfection, and it means that the theory is at fault and needs improvement. There are occasions when mathematical beauty should take priority over [temporary] agreement with experiment.

4.1c Idem, 1956
Inscribed with chalk on the walls of Prof. Dmitro D. Ivanenko's office at Moscow State University, 3 Oct 1956
(http://gnsardan.appfarm.ru/nobel2.html)

> Physical law should have mathematical beauty.

4.1d Idem, 1954
Quantum mechanics and the aether
The Scientific Monthly, vol. 78, p. 142–146

> The fundamental laws of nature correspond to a beautiful mathematical theory.

4.2a Werner Heisenberg, 1970
Die Bedeutung des Schönen in der exakten Naturwissenschaft
Address delivered at the open annual meeting of the Bavarian Academy of Fine Arts, Munich, 9 Jul 1970
Bibliophile German / English edition with three colour litographies by Max Ernst (Stuttgart: Belser-Presse 1971)
Ensemble 2 (Munich: Oldenbourg 1971), p. 228–243 → 235–236
(Gesammelte Werke / Collected Works, vol. C 3, ed. W. Blum *& al*, 1985, p. 369–384 → 376–377)

> Die Bedeutung des Schönen für das Auffinden des Wahren ist zu allen Zeiten erkannt und hervorgehoben worden. Der lateinische Leitsatz "simplex sigillum veri", "Das Einfache ist das Siegel des Wahren", steht in großen Lettern im Physikhörsaal der universität Göttingen als Mahnung für jene, die neues entdecken wollen, und der andere lateinische Leitsatz "pulchritudo splendor veritatis", "Die Schönheit ist der Glanz der Wahrheit", kann auch so gedeutet werden, daß der Forscher die Wahrheit zuerst an diesem Glanz, an ihrem Hervorleuchten erkennt.

> The meaning of beauty in exact natural science
Accross the Frontiers (ed. A. N. Anshen, New York: Harper & Row 1974), p. 166–183 → 174

> The significance of the beautiful for the discovery of the true has at all times been recognized and emphasized. The Latin motto *"Simplex sigillum veri"* —"The simple is the seal of the true"— is inscribed in large letters in the physics auditorium of the University of Göttingen, as an admonition to those who would discover what is new; and another Latin motto, *"Pulchritudo splendor veritatis"* —"Beauty is the splendor of truth"— can also be interpreted to mean that the researcher first recognizes truth by this splendor, by the way it shines forth.

4.2b Werner Heisenberg, 1926
Autobiographical recollection of a conversation with Albert Einstein after Heisenberg's talk at the Berlin Physikalische Kolloquium, 28 Apr 1926
Der Teil und das Ganze (München: Piper 1969), p. 98–99
(Gesammelte Werke / Collected Works, vol. C III, ed. W. Blum *& al*, 1985, p. 3–334 → 98–99)

Ich [Heisenberg] glaube ebenso wie Sie [Einstein], daß die Einfachkeit der Naturgesetze einen objektiven Character hat, daß es sich nicht nur um Denkökonomie handelt. Wenn man durch die Natur auf mathematische Formen von großer Einfachheit und Schönheit geführt wird —mit Formen meine ich hier: geschlossene Systeme von gundlegenden Annahmen, Axiomen und dergleichen—, auf Forme, die bis dahin noch von niemanden ausgedacht worden sind, so kann man eben nicht umhin zu glauben, daß sie 'wahr' sind, das heißt daß sie einen echten Zug der Natur darstellen. […] Sie können mir vorwerfen, daß ich hier ein ästhetisches Wahrheitskriterium verwende, indem ich von Einfachheit und Schönheit spreche. Aber ich muß zugeben, daß für mich von der Einfachheit und Schönheit des mathematischen Schemas, das uns hier von der Natur suggeriert worden ist, eine ganz große Überzeugungskraft ausgeht.

> *Physics and Beyond: Encounters and Conversations* (New York: Harper & Row 1971), p. 68

I [Heisenberg] believe, just like you [Einstein], that the simplicity of natural laws has an objective character, that it is not just the result of thought economy. If nature leads us to mathematical forms of great simplicity and beauty —by forms I am referring to coherent systems of hypotheses, axioms, etc.— to forms that no one has previously encountered, we cannot help thinking that they are 'true', that they reveal a genuine feature of nature. […] You may object that by speaking of simplicity and beauty I am introducing aesthetic criteria of truth, and I frankly admit that I am strongly attracted by the simplicity and beauty of mathematical schemes which nature presents us. You must have felt this too: the almost frightening simplicity and wholeness of the relationships which nature suddenly spreads out before us.