

# Does naturalness imply the ineffectiveness of mathematics?

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# French “epistemology of the LHC”

<http://www.lhc-france.fr>, section “Philosophie”

- E. Klein, “Une introduction aux enjeux théoriques du LHC”
- V. Bontems, “Éloge philosophique du Grand Collisionneur de Hadrons. Esquisses d’une philosophie de l’instrumentation scientifique”
- AG, “On the eve of the LHC: conceptual questions in high-energy physics” arXiv:0806.4268 *Symmetry*. Effective theories. Fine tuning.

AG, “Which fine-tuning arguments are fine?” *Found Phys* (2012) arXiv:0903.4055

AG, “The Effectiveness of Mathematics in Physics of the Unknown” *Synthese* (2017) phil-sci/12950



# Naturalness in 1970s and in 2000

“The naturalness criterion states that [a dimensionless and measured in units of the cut-off] parameter is allowed to be much smaller than unity only if setting it to zero increases the **symmetry** of the theory. If this does not happen, the theory is unnatural.” (G. 't Hooft)

- “question of aesthetics”
- “aesthetic criterion”
- “aesthetic choice”
- “the sense of ‘aesthetic beauty’ is a powerful guiding principle for physicists”

**(Wilson-)Susskind, 1979** Observable properties of a system should be stable against minute variations of the fundamental parameters.

First measures of fine tuning: Barbieri and Giudice 1988; Ellis, Enqvist, Nanopoulos, and Zwirner 1988.

$$\Delta_{BG}(O; p_i) = \left| \frac{p_i}{O(p_i)} \frac{\partial O(p_i)}{\partial p_i} \right|.$$

**Anderson-Castaño, 1995** Observable properties of a system should not be unusually unstable against minute variations of the fundamental parameters.

Problem of global sensitivity in BG. Includes an average over some 'sensible' range of parameters:

$$\Delta_{AC} = \frac{\Delta_{BG}}{\bar{\Delta}_{BG}}.$$

**Athron-Miller, 2007** Fine tuning determines how rare or atypical certain physical scenarios are.



# BSM constructive models

- Supersymmetric: MSSM and the NMSSM family
- Little Higgs
- Extra dimensions
- mSUGRA family
- Technicolor, non-commutative geometry, etc.

## Fine-tunings of constructive models

Standard Model	$10^{34}$
MSSM	1 – 5%
NMSSM	10%
Little Higgs	10%
Simple RS	10%

# As if fine-tuning were a probability of something

- “the likelihood distribution of the theory’s fundamental parameters” Anderson, Castaño
- “a chance to obtain accidental cancellations” Ciafaloni, Strumia
- “since  $\Delta$  and  $\Delta^{(\lambda)}$  represent independent inverse probabilities, they should be multiplied to estimate the total fine tuning  $\Delta \cdot \Delta^{(\lambda)}$  in the model” Casas, Espinoza, Hidalgo

Likelihood or probability of what, in what sense?

# Gedankenfrequenz

**Frequency** because one counts the number of particular occurrences in a class of imaginary untestable numerical scenarios.

**Bayesian** because it's our bet on **future knowledge**.

# Exploring unknown territory

- Physical but unknown
- Effectiveness of **constructive and mathematical** modelling

“The enormous usefulness of mathematics in the natural sciences is something bordering on the mysterious. . . There is no rational explanation for it” (Wigner 1960)

- **If nature is unnatural, is mathematics ineffective?**
- How limited, if at all, is the power of mathematics in building a model of unknown physics?





# Provisional hypothesis

Naturalness is an excessive application of the 'principle theory' approach.

**Einstein** Reflections of this type (on the dual wave-particle nature of radiation) made it clear to me shortly after 1900, i.e., shortly after Planck's trailblazing work, that neither mechanics nor electrodynamics could (except in limiting cases) claim exact validity. By and by **I despaired of the possibility of discovering the true laws by means of constructive efforts based on known facts.**

Constructive vs principle theory distinction (1919).

**Einstein** When we say we have succeeded in understanding a group of natural processes, we invariably mean that a constructive theory has been found which covers the processes in question.

# A better hypothesis

Argument from naturalness is an intrusion of the constructive mode of explanation in a framework which is otherwise fully based on the principle theory approach.

# Blackbox models in physics

AG, “The Effectiveness of Mathematics in Physics of the Unknown” *Synthese* (2017)

- Principle theories AG, [phil-sci/12950](#)
- **S-matrix**
- Effective field theories
- Device-independent models AG, [arXiv:1512.01035](#)

# The beginnings of S-matrix

**Wheeler 1937** The connection which we have obtained between the scattering and disintegration cross sections does not depend for its validity on the accuracy of what we have called the method of resonating group structure.



# Heisenberg reinvents S-matrix

Heisenberg 1942 In view of the later alteration [Abänderung] of the theory, the present investigation attempts to isolate from the conceptual scheme of the quantum theory of wave fields those concepts which **probably** will **not** be **affected by the future changes** [in the theory of elementary particles] and which may therefore represent an integral part [Bestandteil] also of the future theory.



# S-matrix poorly understood

Gregor Wentzel 1947 the S-matrix program is “very incomplete—it is like an empty frame for a picture yet to be painted”



# Pauli's critique

**Pauli 1946** In general I have arrived at the opinion that the  $S$ -matrix is not a concept, of which we may expect that it occurs in a future theory as a primary fundamental concept. It indeed has the character of something complicated and derived and therefore might **hardly be suitable to lead us** beyond the present wave mechanics.

# Provisional conclusion

Anticipated physics is mathematical. However, it might not be elegant.

# Wigner

- Physics has a “somewhat irresponsible” connection with mathematics.
- “When [the physicist] finds a connection between two quantities which resembles a connection well-known from mathematics, he will jump at the conclusion that the connection is that discussed in mathematics simply because he does not know of any other similar connection.”
- “It is true also that the chosen concepts were not selected arbitrarily from a listing of mathematical terms but were developed, in many if not most cases, independently by the physicist and recognized then as having been conceived before by the mathematician.”



## Revised conclusion

Anticipated physics is necessarily mathematical. Beauty will be seen when we'll have found suitable mathematics. And this new mathematics may yet be unfamiliar.



# Back to naturalness

- Naturalness is an intrusion of the constructive mode of explanation in a framework otherwise fully based on the principle theory approach.
- Theoretical frameworks may be revised in search of a better mathematical model. Explanation changes.
- This explanation change preserves constructive elements.
- Naturalness signals a need to look for unfamiliar mathematics.

