PAIDEIA: PHILOSOPHICAL E-JOURNAL OF CHARLES UNIVERSITY

ISSN 1214-8725

Issue/Volume/Year: 4/XIX/2022 (Article)

# Grounding models in full reality: a challenge for interdisciplinary education

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## Abstract

*Ukotvení modelů v plné realitě: výzva pro mezioborové vzdělávání.* – Modely jsou užitečné pro dosažení praktických cílů. Naopak, metafyzické struktury v klasickém smyslu nelze modelovat – natožpak samotné stvoření. Pod vlivem úspěchu modelů došlo ke změně obecného myšlení na úkor více teoretického nebo „kontemplativního" přístupu. Celkovým výsledkem je jemné sebeomezení lidské mysli. Článek dokládá tento obecný obraz pro případ fyziky pomocí dvou běžných zkušeností: formují fyziku, aniž by byly předmětem fyziky. Překonání této propasti vyžaduje inovativní intelektuální výcvik, což je výzvou pro univerzitní vzdělávání.

**Keywords:** model, practical, theoretical, contemplative, mindset, physics, intellectual training, university education

**Klíčová slova:** model, praktický, teoretický, kontemplativní, myšlení, fyzika, intelektuální trénink, univerzitní vzdělávání

## 1 Introduction

'Model' is a key word of the scientific-technological civilization we are living in. Frequently, making and using models is the only way for achieving practical goals in a reasonable time. Yet, a mindset focussed on practical goals all too easily marginalizes more "contemplative" mindsets. At least, mixtures of the practical and the theoretical come about. A good sample of this is given by the first sentences of a doctoral thesis in Theoretical Physics: "Building models to understand how Nature works is all physics is about. Simplifying those models at the same time they describe a wider variety of phenomena is all Theoretical Physics is about."[1]

This wording suggests that, after having taken notice of something to some extent ('Nature'), the mind takes distance from it by furnishing its own conception ('model'). It does so without abandoning the connection, but instead of trying to deepen understanding by establishing rules of how to apply the model to Nature. In the second part of his famous Regensburg Lecture, Benedict XVI goes so far to call that procedure a 'self-limitation of reason' and explicitly points to the epistemological view of Kant.[2]

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[1] GÓMEZ SUBILS, Javier. *Non-perturbative Aspects of Quantum Field Theories from Holography*. PhD diss., University of Barcelona (online), p. 1. Dostupné z WWW: <https://arxiv.org/pdf/2107.01954> (accessed April 10, 2025).

[2] BENEDICT XVI (Joseph Ratzinger). *Faith, Reason and the University – Memories and Reflections* (The Regensburg Lecture, September 12, 2006). (Online). Dostupné z WWW:

This way of managing knowledge has proven successful for achieving *practical* goals, including predictions of future events in the material world. It has made technology achievable. However, the taking distance from the authentic real for the sake of practical goals has its price inasmuch as it marginalizes more "contemplative" mindsets.

Given that building models is, above all, a practice in the natural sciences, it would be relevant for their self-understanding to know in more detail, what the taking distance and the rules of correspondence are *without using models*. In the case of physics, it turns out that taking distance is a sort of disconnection. Doubtlessly, it is desirable to somehow recover that cut-off. In this respect, it turns out that this task requires a sort of innovative intellectual training, thus implying a challenge for university education with its interdisciplinary dynamics.

This article tries to substantiate the taking distance in physics, because it is the natural science which is most clearly divided in two bodies of knowledge: experiences and mathematical theories. To date, they are only united in the experimenter-physicist. Nobody knows whether mathematical theories are somehow pre-figured in material things. This situation makes it understandable that the Kantian epistemological views have found easy entrance in physics. This is shown in the next section quoting influential philosophers and physicists (2.).

Attempting a recovery directs the attention to two states of affair within ordinary experience that shape physics, but are not properly results of physics. One of them is an active intervention of the scientist and leads straightforwardly to the cut-off mentioned (3.). The other state of affair is related to material things and is another sort of lack (4.). While these two states of affair cannot be incorporated into physics, they might be good candidates for being the basis of a larger framework. In that case, there would be necessary substantial reassessments. This, in turn, should be the object of the mentioned innovative intellectual training (5.)

## 2 The Impact of Kantian Epistemology in Physics

The close relationship of the general mindset in physics with Kant's basic epistemological view is indicated by means of some quotations from Immanuel Kant himself, followed by Heinrich Hertz, Albert Einstein, Karl Popper and Stephen Hawking.

Kant (1724–1804) sees the basic relationship between experience and thought as follows: "Although all our cognition commences *with* experience, yet it does not on that account all arise *from* experience."[3] And "we ourselves bring into the appearances that order and regularity in them that we call nature, and moreover we would not be able to find it there if we, or the nature of our mind, had not originally put it there".[4]

<https://www.vatican.va/content/benedict-xvi/en/speeches/2006/september/documents/hf_ben-xvi_spe_20060912_university-regensburg.html> (accessed April 10, 2025).

[3] KANT, Immanuel. *Critique of pure Reason*. Cambridge: Cambridge University Press, 1998 (online), B1. Dostupné z WWW:<https://cpb-us-w2.wpmucdn.com/u.osu.edu/dist/5/25851/files/2017/09/kant-first-critique-cambridge-1m89prv.pdf> (accessed April 10, 2025).

[4] *Ibid.*, A125.

And also: “Thus as exaggerated and contradictory as it may sound to say that the understanding is itself the source of the laws of nature, and thus of the formal unity of nature, such an assertion is nevertheless correct and appropriate to the object, namely experience.”[5]

It is known from the diaries of Heinrich Hertz (1857–1894) that he was an avid reader of Kant’s works. He is one of the fathers of the concept of ‘model’ in physics, which he motivates and describes as follows: “The most direct, and in a sense the most important, problem which our conscious knowledge of nature should enable us to solve is the anticipation of future events, so that we may arrange our present affairs in accordance with such anticipation. (…) In endeavouring thus to draw inferences as to the future from the past, we always adopt the following process. We form for ourselves images [*innere Scheinbilder*] or symbols of external objects; and *the form which we give them is such that the necessary consequents of the images in thought are always the images of the necessary consequents in nature of the things pictured*.”[6]

After settling the basic property of a model, some general characteristics follow: “The images which we here speak of are *our conceptions* of things. With the things themselves they are in conformity in *one* important respect, namely, in satisfying the above-mentioned requirement. For our purpose it is not necessary that they should be in conformity with the things in any other respect whatever. As a matter of fact, we do not know, *nor have we any means of knowing*, whether our conceptions of things are in conformity with them in any other than this *one* fundamental respect. (…) The images which we may form of things are *not determined without ambiguity* by the requirement that the consequents of the images must be the images of the consequents.”

Einstein’s adherence to Kant’s epistemological view is obvious: “The theoretical attitude here advocated is distinct from that of Kant only by the fact that we do not conceive of the ‘categories’ as unalterable (conditioned by the nature of the understanding) but as (in the logical sense) free conventions. They appear to be a priori only insofar as thinking without the positing of categories and of concepts in general would be as impossible as is breathing in a vacuum.”[7]

Accordingly, experiences have no influence on the formation of concepts. Rather, these must be ‘posited’. The positing of concepts is orientated by what Einstein calls ‘intuition’: “The concepts and propositions get ‘meaning’, viz., ‘content’, only through their connection with sense-experiences. The connection of the latter with the former is purely intuitive, not itself of a logical nature.”[8]

Intuition and positing are bound by their goal, namely to achieve the greatest possible completeness in the recording of experience as well as conceptual ‘economy’: “The system of

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[5] *Ibid.*, A127.

[6] HERTZ, Heinrich. *The Principles of Mechanics Presented in a New Form.* London: Macmillan, 1899, p. 2; emphasis added (online). Dostupné z WWW: <https://archive.org/details/principlesofmech00hertuoft> (accessed April 10, 2025).

[7] EINSTEIN, Albert. Remarks to the Essays Appearing in this Collective Volume. In SCHILPP, Paul A. (ed.) *Albert Einstein – Philosopher and Scientist.* La Salle, IL: Open Court, 1995, p. 674.

[8] EINSTEIN, Albert. Autobiographical Notes. In SCHILPP, Paul A. (ed.) *Albert Einstein – Philosopher and Scientist.* La Salle, IL: Open Court, 1995, p. 13.

concepts is a creation of man together with the rules of syntax, which constitute the structure of the conceptual systems. Although the conceptual systems are logically entirely arbitrary, they are bound by the aim to permit the most nearly possible certain (intuitive) and complete co-ordination with the totality of sense-experiences; secondly they aim at greatest possible sparsity of their logically independent elements (basic concepts and axioms), i.e., undefined concepts and underived [postulated] propositions."[9]

The following quote comes from Karl Popper (1902–1994) and is something like the intellectual legacy of his work *The Logic of Scientific Discovery* (1935): "Even the careful and sober testing of our ideas by experience is in its turn inspired by ideas: experiment is planned action in which every step is guided by theory. We do not stumble upon our experiences, nor do we let them flow over us like a stream. Rather, *we* have to be active: *we* have to 'make' our experiences. It is *we* who always formulate the questions to be put to nature; it is *we* who try again and again to put these questions so as to elicit a clear-cut 'yes' or 'no' (for nature does not give an answer unless pressed for it). And in the end, it is again *we* who give the answer, it is *we* ourselves who, after severe scrutiny, decide upon the answer to the question we put to nature."[10]

The last quote stems from the well-known physicist Stephen Hawking (1942–2018): "There is no picture- or theory-independent concept of reality. Instead we adopt a view that we call model-dependent realism: the idea that a physical theory or world picture is a model (generally of a mathematical nature) and a set of rules that connect the elements of the model to observations..."[11]

"According to the idea of model-dependent realism (…) our brains interpret the input from our sensory organs by making a model of the outside world. We form mental concepts of our home, trees, other people, the electricity that flows from wall sockets, atoms, molecules, and other universes. These mental concepts are the only reality we can know. There is no model-independent test of reality. It follows that a well-constructed model creates a reality of its own."[12]

It can reasonably concluded that the mindset of the vast majority of physicists is close to the stances just quoted. In particular, this view of models in physics implicitly carries the message that, according to these physicists, experience has little or no cognitive content. The epistemological position taken in this article sees, on the contrary, experience as having a high cognitive content. In order to avoid misunderstandings, models are not taken into account in this article. It remains a demanding task to find out whether mathematical laws are, and if so, to which extent, pre-formed in individual material things. Then and only then, mathematical laws would be also laws of nature.

[9] *Ibid.*
[10] POPPER, Karl R. *The Logic of Scientific Discovery*. London: Routledge, 2002, p. 280, emphasis by the author (online). Dostupné z WWW: <https://www.raggeduniversity.co.uk/wp-content/uploads/2014/03/popper-logic-scientific-discovery-ilovepdf-compressed.pdf> (accessed April 10, 2025).
[11] HAWKING, Stephen, MLODINOW, Leonard. *The Grand Design – A New Explanation of the Universe.* New York: Bantam Books, 2010, p. 42.
[12] *Ibid.*, 172.

ISSN 1214-8725

## 3 Ambivalence: its Positing and its Practical Elimination

The first of the two items of everyday experience announced in the introduction is linked to measurement, which is the simplest form of a physical experiment. More generally, a physical experiment is an intervention by the experimenter in the natural course of material processes in order to systematically investigate material things ('objects') by other material things ('apparatuses'). The roles of 'object' and 'apparatus' are correlative; there is no experiment with two objects or two apparatuses. Now, according to the general view, a material thing neither has one of these functions *by itself* nor is it somehow predisposed *by itself* to one of them. The functions 'object' and 'apparatus' per se, with their correlative asymmetry, are therefore exclusively a positing of the experimenter.

Moreover, the material thing destined to be an apparatus is, as something *material*, on the same level as the material thing destined to be the research object. Therefore, the apparatus could, in principle, also function as an object. This is why the assignment of the correlative functions to both sides remain undetermined even after they have been distinguished from each other. The two correlative functions can be occupied by the two sides in *two* ways and thus define *two different* experiments. In other words, there is an 'ambivalence' from the material things' point of view that can be eliminated only by the experimenter. As a rule, it is the experimenter's research interest that provides the criterion for the choice of the assignment. But by choosing one of the two possible assignments the experimenter necessarily eliminates the other. It is true that the other occupation can be chosen at another time for the 'complementary' experiment, but then to the exclusion of the first assignment.

Therefore, the mutual exclusivity of these two assignments in the same experiment is a fundamental characteristic of experimentation in general. It is not pre-formed in the material things, hence exclusively the result of the experimenter's intervention. Setting the ambivalence and eliminating it for a particular experiment thus brings a gain in knowledge that presumably cannot be acquired in any other way. However, this gain is bought at the price of not gaining knowledge about what the other experiment would yield at the same time. Thus, physical knowledge is in a peculiar way partial, and this stems from the operating experimenter.

Additionally, it is precisely through the experimenter's positing of ambivalence and its elimination that physical knowledge has a *subjective* character. True that any number of experimenters can carry out any number of similar experiments, at any place at any time, and that these experimenters can communicate with each other and also determine whether and to what extent they have achieved the same results: intersubjectivity. But each of them carries out 'his' setting of ambivalence and eliminates it by his choice.

The primary purpose of the functions 'object' and 'apparatus' is to make it possible for the experimenter to connect processes of material things to a (mathematical) model. Then, the model can 'run ahead' of the real process, and the prediction of the model can then be checked by applying again the apparatus to the object. Only this is how the mathematical construction becomes a *physical* model. However, once the model is considered 'appropriate', 'reliable' or even 'accurate', the apparatus is usually not re-applied to the object. In practice, this loosens the model's ties to experiments, which then seems to have an independence or objectivity that

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it actually does not possess. Physical models only gain objectivity when it becomes clear that and how mathematics is *pre-formed* in material things.

In the usual outline of the relationship between theory and experiment, the setting of an ambivalence with the subsequent elimination of one of the two alternatives and its influence on the nature of the knowledge acquired is hardly ever mentioned. Rather, the usual brief characterisation of the intertwining of experiment and theory is limited to referring to a kind of dialectics in the acquisition of physical knowledge: the experimenter constructs a theory on the basis of what he already knows, uses it to design experiments, and in turn uses their results to confirm, modify or extend an existing theory. Thus, ambivalence is well known as a fundamental characteristic of physical research on the one hand, but is practically ignored on the other.

That situation is stabilized by experimental practice: the research object is so much in the foreground that apparatuses are practically only regarded as aids and not equally as potential research objects. The difference between the object's and the apparatus' order of magnitude has a similar effect, since nobody would even think for a moment about investigating the detectors of a particle accelerator with the accelerated particles, or a measuring tape with a building.

The actual performance of experiments requires, after setting and eliminating the ambivalence, four further reductionisms: the *termination* of the experiment, its *spatial limitation*, the *distinction between the experimental process and what is regarded as its result*, and the *predominant attribution of the result to the object*. In contrast, the course of nature is neither interrupted nor categorised in any other way. These reductionisms, too, are interventions by the experimenter only, but the losses caused by them may be considered less important than the loss caused by the ambivalence and its elimination.

## 4 Elementary Particles, Solid Bodies and Collective Self-Disclosure

Summarising experiments with elementary particles and the basic qualitative features of their results from the perspective of pre-scientific experience yields the following statement: *elementary particles are discovered and classified with the help of solids, and solids in turn consist of elementary particles*. This statement signifies that nature as a whole has a 'language of self-communication': elementary particles participate in the discovery and classification of their own kind – a *collective self-disclosure*. This language of nature has its own *real vocabulary*; two basic *words* are ambivalence and the just mentioned collective self-disclosure.

The latter is an enormous finding indeed, notwithstanding its formulation in simple terms. It is deeply opposed to the epistemological view expressed in section 2. Without excluding mathematics, its way of thinking is far removed from a way of thinking that is heavily relying on mathematics. In fact, how should one mathematically represent the sort of self-referentiality in the above statement? On the other hand, it is clear at first glance that several clarifications are necessary. The most obvious concern the topics of spatiality, interaction and the agglomeration of elementary particles to atoms and solid bodies.

ISSN 1214-8725

## 5 Conclusion

In physics, applying models involves experiments. Experiments necessarily contain a serious incompleteness – the elimination of an ambivalence created by the scientist. Restoring the completeness requires going back to the situation *before* introducing the ambivalence. The starting point for that endeavour might well be the collective self-disclosure. The task most probably would include a sort of conceptual foundation of experiments as well as mathematical theories into a larger framework.

The customary way of thinking is tied to mathematical laws and, therefore, is hardly in conditions to perform that task. An innovative and independent approach is needed, which requires considerable intellectual independence and openness to alternative frameworks. In view of the importance of physics, this is not merely one issue among many. It is a challenge that should be taken into account by professionals of university education.

**ISSN 1214-8725**

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(*Dr. Rudolf Larenz*, jaderný fyzik a člen Opus Dei, je nezávislým badatelem v Helsinkách.)