Reflecting Particle Physics

On the relationship between the natural sciences and the humanities in the research group "The Epistemology of the Large Hadron Collider"

"

Gregor Schiemann

Department of Philosophy and
Interdisciplinary Centre for Science and Technology Studies

Gaußstr. 20
D-42119 Wuppertal
Germany

schiemann@uni-wuppertal.de

My talk will address the relationship between the philosophy of physics and physics using the example of an interdisciplinary research group I represent. The research group studies the knowledge and its conditions in high-energy physics. The members include physicists as well as historians, sociologists and philosophers of science. The center of the Group is located at University of Wuppertal, but the members of the group are distributed altogether across 3 countries and 7 universities.

The status of the philosophy of science in this context exhibits certain similarities with that of the history and sociology of science. I call these three disciplines in what follows "science-reflective" disciplines, although I would like to add immediately that by this I do not mean to imply that physics does not involve reflection. But whereas the activity of physics can by no means be reduced to reflection on its work, the science-reflective disciplines do nothing else than reflect: Either they reflect on the historical, social and philosophical questions of other sciences or they reflect on themselves. In the research group the scientific reflection is limited to theoretical questions. Practical questions such as those concerning scientific ethics or scientific responsibility are excluded.

Interdisciplinary research groups combining physics and disciplines that reflect on science are quite rare. In Germany, our research group is at present the only interdisciplinary collaboration of this kind funded by the German Research Foundation DFG, which currently funds 173 research groups. This is not surprising in the case of the sciences, because normally they do not require the science-reflective disciplines in a comparable way to that in which the latter normally depend on them – a circumstance expressed in a pointed way in the often used comparison that the philosophy of science is for the sciences what ornithology must be for the birds. However, as a general rule the work of the science-reflective disciplines is not conducted in an interdisciplinary way either, insofar as one does not generally need to engage actively in research in order to reflect upon it. This relationship between reflection and its object is not typical of scientific reflection: Art criticism no more need be able to produce art than social theory must actively participate in social processes.

I will begin by briefly introducing the research group. In the second part I will attempt to characterize the relationship between physics and the philosophy of physics in the context of the work of the research group. As I conceive it, the philosophy of physics functions not only as a bridge between physics and the humanities but also and on the contrary as some sort of arena for them. Philosophy of physics is also a part of the humanities. As such, its close proximity to physics is highly ambivalent: It not only exhibits shared points of contact with physics, but also becomes directly aware of differences that in part prevent communication. In the concluding third part, I would like to present a hypothesis concerning the future of high-energy physics as an example of reflection on science that combines positions from physics and the philosophy of science. I will formulate it by drawing upon elements of Thomas S. Kuhn’s theory of scientific development. From the perspective of physics and of the philosophy of science, this hypothesis suggests that high-energy physics is a peculiar discipline: It has an extremely well-confirmed paradigm – the so-called Standard Model of particle physics – which for some time has been unable to solve extraordinarily far-reaching and generally accepted theoretical problems.

1. “The Epistemology of the Large Hadron Collider”

The name of the research group is “The Epistemology of the Large Hadron Collider.” The Large Hadron Collider (abbreviated LHC) at the European Organization for Nuclear Research CERN in Geneva is in various respects the largest scientific measurement instrument ever built. By bringing about collisions between particles – so-called hadrons, of which protons are a well-known representative – accelerated at high energies, the aim is to investigate the fundamental structures of matter in domains that are 100 million times smaller than the hydrogen atom, which with a diameter of one 10 millionth of a meter is already very small.

Current knowledge about the fundamental structures of matter is represented through a combination of theories and models, namely, the aforementioned Standard Model. The LHC was developed to examine predictions of the Standard Model and to contribute to the discovery of new phenomena whose explanation could help to solve the theoretical problems that the Standard Model has been unable to solve to date. Theories and models beyond the Standard Model already exist that predict such phenomena. Their confirmation could lead to a fundamental change in the foundation of physics. The experiments conducted to date at the LHC have in essence led to the discovery of the Higgs boson particle predicted by the Standard Model – an elementary particle that occurs during the generation of mass. The predictions of new phenomena have not been confirmed thus far.

A DFG research group consists of two main elements: the guiding question that focuses the entire work of the research group on a single topic, and the projects whose work is supposed to contribute to solving the guiding question, but which also have an independent character and cooperate with each other. The guiding theme is located in the philosophy of science and concerns the pronounced tension between simplicity and complexity in high-energy physics. The Standard Model exhibits perhaps unique simplicity in the field of scientific theories in that it explains the diverse manifestations of matter and forces that exist on the very small scale in terms of a few elementary components. The reductionism achieved in high-energy physics is perhaps without parallel in other disciplines. But the experimental side of high-energy physics also exhibits astoundingly simple features. Insofar as the LHC is a measuring instrument that confirms or disproves predictions, a clear and thus simple distinction can be made between theory and experiment. The lack of experimental confirmation of the predictions of alternative theories has led to an abrupt diminution of their importance. The complex theoretical and experimental structures stand in contrast with the elements of simplicity. The relationships between the different theories, between the theories and their models and between different models and the technical and practical conditions of the experiments can be characterized as complex.

The tension between simplicity and complexity raises many reflective questions, some of which are epistemological and others ontological in nature. Only a few of them can be mentioned here: Is it possible to reduce the complex structures of matter still further to simple elements, or do they have an irreducibly complex character? Is the matter that exists on the very small scale simple at all and not rather complex? Can there be a single theory of matter or are different theories necessary or possible?

The research group has six projects: one project each in the sociology and the history of science and four projects in the philosophy of science. All of the projects are led by at least one physicist and one representative of a science-reflective discipline.

The project in the sociology of science deals with aspects of the social structure of the LHC, at which around 3,200 staff and over 10,000 guest researchers work. Among the topics in the sociology of science is the question of how the achievements of one person can still find recognition in this complex structure.

The history of science project explores the history of the simplifying graphical representation of complex physical processes using so-called Feynman diagrams as well as the concept of virtual particles involved.

The projects in the philosophy of science focus on the following topics:

Two projects deal with the complexity of competing models, one in the field of gravitational phenomena and the other in the field of models that in general seek to remedy the shortcomings of the Standard Model.
A further project analyses the relationship between simulation and experiment, where simulation is understood as an instrument for simplifying complex theoretical or experimental data.

The theme of the final project is the principle of so-called naturalness as a simplifying method of modeling. A model counts as natural if its parameters are not dependent on the parameters of far distant dimensions.

The preparatory studies for the work of the research group were still completely shaped by the expectation that the foundations of physics would undergo a fundamental change, an expectation driven by the hope for discovery of new phenomena that are either already predicted by theories beyond the Standard Model or point to as yet completely unknown structures. The initiative to form the research group also came essentially from physicists who needed philosophical support in processing the hoped-for developments or alternatively their failure to materialize. Physicists require conceptions from the human sciences and human scientists require detailed physical knowledge not in order to produce, but in order to gain a better understanding of the research results at the LHC. Taken as a whole, the projects of the research group are designed to take this concern into account. An internal structure of the University of Wuppertal – namely, the Interdisciplinary Centre for Science and Technology Studies – proved to be crucial in facilitating communication between physics and the science-reflective disciplines.

Around the same time as the research group took up its work, the negative results of the experiments at the LHC, that is, the failure to discover new phenomena, began to accumulate. It became apparent that even a continuation of the experiments would probably not lead to the expected transformation of the foundations of empirical knowledge. The change in expectations was documented by the research group through surveys conducted among the physicists (Chall et al. 2018, Mättig and Stöltzner 2018) . Especially for the projects that are directly connected with the expected change, the result was an opportunity to conduct a science-reflective study of the dynamics of physical knowledge and reflection in real time.

In the last part of my talk I will reflect on the changes in expectations as a supposed manifestation of a crisis in high-energy physics. Before this I come my second part, in which I try to characterize the relationship between physics and philosophy of physics in the context of the research group.

2. On the Relationship between Physics and the Philosophy of Physics

A more precise description of the relationship between physics and science-reflective disciplines requires greater weight to the specific features of these disciplines. In contrast to the history and the sociology of physics, the philosophy of physics is generally more directly concerned with the content and truth of current physical knowledge. Here I will limit myself to characterizing the relationship between this discipline and physics. It is useful for the purposes of the philosophy of science to distinguish between the philosophy of science in general, which deals with cross-disciplinary questions, and the philosophy of individual sciences. The relevance of this distinction has only become apparent in recent decades (Reydon and Lohse (eds.) 2017 and Kuhlmann 2017). The ongoing process of differentiation within science has led to the emergence of specialized individual sciences to such an extent that the issues they raise for the philosophy of science can no longer be comprehended exclusively within the framework of the general philosophy of science.

In the following I will deal with the general philosophy of science only to the extent that it is relevant for the philosophy of physics, and in particular for the philosophy of high-energy physics. High-energy physics is distinguished from a number of other fields of physics by the highly developed reductionism already mentioned and its engineered experiments, which lead to the discovery of extremely complex phenomenon structures due to the high energies employed.

The philosophy of physics is a two-disciplinary enterprise in terms of education. On the one hand, reflection on physics requires knowledge of this science that can only be acquired by studying physics. On the other hand, the philosophy of physics employs text-related methodologies like those commonly used in the humanities. Definitions, analyses of meaning and the reconstruction of arguments are among the indispensable tools of the philosophy of physics (See Kuhlmann and Pietsch 2012).

Its two-disciplinary character opens up a broad field of possibilities for the philosophy of physics. The philosophy of physics may be indistinguishable from theoretical physics (as is shown, for example, by the journal *Foundations of Physics*). The subject matter of the philosophy of physics and of theoretical physics is not nature, but knowledge about nature. Whereas contributions that blur the boundary between philosophy of physics and theoretical physics represent the typical format for the studies of the research group, in the philosophy of physics as a whole they represent more the exception. *The philosophy of physics is clearly distinguished as a general rule from the methods of physics by its text-related methodology and the systematic interest that is characteristic of philosophy.*[1]

In spite of the close cooperation with the physicists, this disciplinary difference – which is related to C. P. Snow’s two cultures – is also important for the research group. I would like to provide two examples by way of illustration. The first concerns how the research in the philosophy of physics

[1] Against Esfeld 2012, Wüthrich 2017

produced by the members of the research group to acquire academic qualifications should be classified (specifically, doctoral and postdoctoral theses – something similar holds in the history and the sociology of science). From the perspective of physics, this research clearly belongs in most cases to the field of philosophy and normally commits the researchers to a career in philosophy. From the point of view of philosophy, the assessment of the research in question is not so clear. Whereas many philosophers, who are not concerned with the philosophy of science, would consider the work of the members of the research group to be more physical, the philosophers of science are generally aware of the non-physical character of the studies in question. *In my opinion, the philosophy of science bears the burden of an increasing specialization within physics that does not allow sufficient room for possible and also necessary reflection within this discipline.*

The second example concerns the themes and methods of the philosophy of physics used by the research group. Quite diverse approaches to studying physical knowledge are represented within the philosophy of physics. A range of these approaches are not employed by the research group for good reasons. The approaches in question are characterized by a philosophical research interest aimed at conceptual articulation and formal clarification of theoretical structures. But while conceptual precision is all-important in philosophy, in physics certain kinds of conceptual imprecision that allow for different interpretations can be of use, especially in unclarified research situations. Whereas some directions in the philosophy of science take their orientation from strict logical deductive relationships in reconstructing the structures of physical theories, theory formation in physics includes pragmatic elements geared to the goal of the predictability of real phenomena. These different disciplinary interests can make interdisciplinarity difficult, if not impossible.

When it comes to communication between philosophy and physics, the members of the research group have found topics and methods located in the transitional area between the theoretical domains of the two disciplines to be suitable, with all topics being characterized by a pronounced reference to experimental experience. Research on competing models and on naturalness as a principle of modelling is conducted with a view to the experimental results of the LHC; the project on simulation is directly concerned with the role of simulations in experiments.

I would like to offer as an example a subproject on the role of computer simulations in experiments in which I am involved myself. Whenever I speak simply of simulations in what follows, I always mean computer simulations. The experiments at the LHC are linked in a particular way with these simulations. On the one hand, theoretical knowledge, which is a precondition for experiments, and empirical knowledge that has already been acquired through experiments are fed in simulations. On the other hand, however, the conduct of the experiments often depends on simulations. For example, simulations are used to construct the experimental devices, calibrate the measuring instruments and analyze the measurement results. In this way, the imitation of experiments through simulations becomes part of the experiments.

From the close interrelationship between simulation and experiment, as exhibited by the extent to which simulations were used in the discovery of the Higgs boson, Margaret Morrison concluded that this discovery would not have been possible without simulations (Morrison 2015, 287). Simulations, she argues, are a necessary condition of the experiments not only for practical but also for “logical and causal” reasons (Morrison 2015, 288). Here I do not want to deny that certain scientific findings cannot be obtained without simulations. Rather, the question is whether the discovery of the Higgs boson, and perhaps of other elementary particles, belongs to this class of scientific findings, assuming it exists. If simulations were indispensable for conducting high-energy experiments, it would be possible that experience would depend on prior knowledge that could no longer be identified as such in the experimental results.

In the first place, we can show that the theoretical requirements for the preparation of the experiment that led to the discovery of the Higgs-Boson, depend to only a limited extent on simulations. Furthermore, it can be shown which simulations used in experiments can be replaced or even rendered dispensable by experiments or calculations independent of simulations. Three cases can be distinguished here.

For some of these simulations, they can be substituted or dispensed with without changing the experimental conditions. For some decay channels of the Higgs boson, for example, the simulated calculation of the data background can be replaced by already available experimental data.

In the case of other simulations, it is quite conceivable that they could be substituted or dispensed with under current experimental conditions but this is not realized simply for practical reasons. Thus, in developing the detectors, the measuring instruments could be optimized without simulations at the cost of a longer preparation time, where the extension would be at most of the order of a few years.

Finally, in some cases becoming independent from simulations might only be possible "in principle," but would not be feasible. It would be possible to dispense with simulations only "in principle" if, for example, the corresponding non-computer-supported calculation could not be performed by a research community within a human lifetime. To date, however, we have not found such only-in-principle-cases.

By asking how far it would be possible to carry out the experiment to detect the Higgs boson without simulation, the argumentation acquires in part the counterfactual content of thought experiments, which, as it happens, are also similar to simulations (Beisbart 2012, Boge 2018).[2] Our hypothesis is that the discovery of the Higgs boson – putting it bluntly – was so simple that it would also have been possible without the use of simulations.

This typical example of the reflections of the research group combines the modes of reflection specific to philosophy and to physics. Philosophy is needed, for example, to make the conceptual differentiation between simulation and experimentor to apply the method of thought experiments to the theory of science. Physics is required in order to make an informed assessment of the actual or possible independence of experiments from simulations. This brings me to my third part which deals the future of high energy physics.

3. Reflective Particle Physics

The expectations that the foundations of physics would undergo a fundamental change that provided a motivation for establishing the research group can be described with Thomas S. Kuhn's theory of scientific development only to a limited extent, but for that very reason in an illuminating way. Kuhns theory seems to be more popular among physicists than among philosophers of science, who often consider it outdated.

[2] Simulations are similar to thought experiments and, like the latter, are not necessarily counterfactual.

The Standard Model of particle physics coheres with a group of meanings of the concept of a paradigm that guide normal scientific research as a “disciplinary matrix.” The Standard Model includes all known elementary particles, describes almost completely their physical properties, has received overwhelming confirmation, and provides to the present day the framework for solving numerous normal scientific research tasks.

But there are also the severe problems already mentioned. For some problems it might be possible that they will be solved within the framework of the Standard Model after all. Among the probably fundamental problems whose solution within the Standard Model seems rather questionable, some concern already known particles, whereas others have resulted from failed attempts to extend the Standard Model to other fields of application. Some of the problems can be described as anomalies in the Kuhnian sense, such as the fact that neutrinos are not massless or the deviating anomalous magnetic dipole moment of the muon.

Theories have been proposed for solving the problems of the Standard Model that integrate the Standard Model into a more comprehensive system of structures, examples being supersymmetry or the theories of extra dimensions. As extensions of the standard model, they can be understood as further developments of the existing paradigm; however, they could also prove to be candidates for a new paradigm of high-energy physics. The loss in importance of these theories caused by the recent failure to discover the phenomena they predicted has given rise to perplexity among physicists. Referring to Kuhn’s theory of scientific development, the head of the theoretical physics department at CERN, Gian Francesco Giudice, speaks of a current crisis in particle physics, which he expects will end in a new, as yet undefined paradigm. For Giudice, the crisis is marked by an increase in reflection by comparison with the enterprise of normal science (Giudice 2017).

One can agree with this assessment of the situation only in part. Giudice is right to highlight the loss of confidence within the discipline that both, the Standard Model and its proposed extensions or alternatives, have experienced. However, he underestimates the relevance of the Standard Model for understanding matter and the fundamental interactions in the universe. The crisis in question is a high-level crisis of an extremely successful discipline. The crisis has, on the one hand, a far-reaching character of physical reflection. It not only shows an increased interest in historical, ontological and methodological questions in its own subject area, but also increasingly refers to neighboring subject areas, among which cosmology is of particular interest for high-energy physics On the other hand, tendencies toward a more technical as opposed to a reflective reaction to the current crisis are also apparent. This includes the increasing shift toward a less theory-bound and less model-dependent analysis of experimental data. A suitable means would be, for example, the search for as yet unrecognized data structures using machine-learning systems. The indications pointing to a positivist renunciation of explanation are multiplying (Hossenfelder 2017).

That the crisis will come to an end with the establishment of a new paradigm is not the only possible assumption. Research into the foundations of visible matter and the forces that mediate it is undoubtedly far advanced. The acquisition of new knowledge could require energies whose generation is beyond the limits of what is currently technically feasible on earth. Against the background of what has already been achieved, it does not seem absurd to claim that the Standard Model of high-energy physics may be somewhat similar to a so-called closed theory as described by Werner Heisenberg. Closed theories are only valid in a limited domain and can no longer be essentially improved through small changes. They have reached the end of their innovative development and are destined to remain valid and unchanged in their object domains in the long term. Examples of closed theories for Heisenberg were, among others, classical mechanics and electrodynamics (Schiemann 2008 70 ff.).

If the Standard Model continued to prove its worth as in the past, but the theoretical structural problems and supposed anomalies do not find solutions, then a form of normal science might exist that not only had a paradigm, but was equally confronted with questions whose answers, assuming they were possible, would call for considerable conceptual and technological developments. Could a stable and successful paradigm permanently coexist with acknowledged profound problems? Would this represent an approach for the type of development of knowledge at the limits of what we know?

These questions point toward a mature, as it were permanent reflection on science in which scientific disciplines and the science-reflective disciplines that deal with them participate in a similar manner. From a theoretical perspective, the science-reflective disciplines might also perform a therapeutic function in this discourse by helping science to coexist well with problems.

Acknowledgement:

I profited highly from discussions with colleagues from the Research Group ’Epistemology of the LHC’ funded by the DFG under grant FOR 2063.

Literature

Beisbart, Claus (2012): How can Computer Simulations Produce new Knowledge? Euro Jnl Phil Sci (2012) 2:395-434

Boge, Florian (2018): Why Computer Simulations are not Inferences, and in What Sense they are (not) Experiments. Manuscript.

Chall, Cristin, Martin King, Peter Mättig, and Michael Stöltzner (2018): From a Boson to the Standard Model Higgs: A Case Study in Confirmation and Model Dynamics. Manuscript.

Esfeld, Michael (2012): Vorwort, in: M. Esfeld (Ed.), Philosophie der Physik. Frankfurt a.M.

Giudice, Gian Francesco (2017): The Dawn of the Post-Naturalness Era. https://arxiv.org/abs/1710.07663

Kuhlmann, Meinard (2017): Allgemeine Wissenschaftsphilosophie und die Philosophien der Einzelwissenschaften, in: Lohse, S., und T. Reydon (Ed.): Die Philosophien der Einzelwissenschaften. Hamburg, S. 17-50.

Kuhlmann, Meinard, and Wolfgang Pietsch (2012). What is and why do we need Philosophy of Physics?, Journal for General Philosophy of Science 43, 209-214.

Lohse, Simon, and Thomas Reydon (Ed.) (2017): Grundriss Wissenschaftsphilosophie. Die Philosophien der Einzelwissenschaften. Hamburg.

Morrison, Margaret (2015): Reconstructing Reality. Models, Mathematics, and Simulations. Oxford University Press.

Mättig, Peter, and Michael Stöltzner, (2018): Model Choice and Crucial Tests. On the Empirical Epistemology of the Higgs Discovery. https://arxiv.org/abs/1806.09201

Schiemann, Gregor (2008): Werner Heisenberg, München.

Wüthrich, Christian (2017): Philosophie der Physik, in: Lohse, S., und T. Reydon (Ed.): Die Philosophien der Einzelwissenschaften. Hamburg, S. 17-50.