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Introduction

Michael Heidelberger and *Gregor Schiemann*

Since early modern times, the significance of hypothesis in natural science has been judged in widely different ways and has become the source of many controversies. The purpose of this volume is to illuminate some general lines of development of those debates by treating cases from the history of science and philosophy. The case studies presented here deal especially with physics, astronomy, mechanics and chemistry as well as with problems posed for mathematical theories of natural science in general.

Taken together, these cases show that the role hypothesis played and plays for natural science is of central importance for the manner in which a science conceives of itself and its own methodology. Accordingly, different concepts of science entail different attitudes towards hypothesis, both in the history of science and in the discourses of the philosophy of science. The significance attributed to hypothesis is, so to say, a kind of a litmus-paper for the changing and diverging conceptions of science of the scientific actors themselves, as well as of the philosophers who reflect upon the sciences.

If we focus, though, on contemporary discussions, the concept of hypothesis seems to be taken almost as univocal. Historians and philosophers of science as well as scientists themselves seem more or less to agree on its meaning. A hypothesis is normally taken as a conjecture that is expedient for the gain of knowledge. Sometimes, this definition is accompanied by the conviction that the truth value of a hypothesis will finally be established with further research. We also find the view, however, that the hypothetical character of certain propositions will never be eliminated. These we can call "metaphysical hypotheses". Not only single propositions are called hypotheses, but also theories, clusters of them or even the whole of scientific knowledge. It is almost common sense in the philosophy of science to generally attribute a hypothetical character to empirical theories. According to this view, conjectures are not only useful for the production of knowledge, but scientific theories are nothing but a collection of conjectures. There are powerful and acknowledged arguments for this, both of a systematic and historical nature. In a systematic sense, the hypothetical nature of scientific theories relates to the insolubility of the problem of induction. The truth of general propositions a theory comprises can never be deduced from experience, the famous opposite opinions of Newton and Ampère notwithstanding. Yet experience and theory cannot be separated sharply from each other and their inseparability is a further reason for their insecure make-up. It seems to be impossible to identify the culprit for an error in the entangled net of experience and theory. This circumstance is in agreement with the historical claim that theories hardly ever lost their validity as a result of being conclusively refuted, but rather because their followers died out in the course of time – this being another support for the conclusion that the claim of scientific propositions to truth cannot be resolved.

It is now exactly this common sense in regard to the hypothetical character of science that can go with very different evaluations of its significance. It seems that the different views can be grouped in at least three ideal types. The first one takes the hypotheticity of science as being of highest significance. The conjectural character of scientific theories is taken as their hallmark. It follows that a true theory is impossible and that science must live with the perpetual susceptibility to error, and thus with permanent revision and a forever undecided truth-value. The high esteem of the provisional character of science leads to a revaluation of ignorance and uncertainty. The second type of evaluating hypotheticity to be distinguished from the first takes hypotheticity for an important and inevitable mark of science as well. Yet this type does not infer that we should renounce any claim to truth, but, on the contrary, to endorse it. According to this view, hypotheses can always come closer to the truth. The certainty of propositions can be improved, their domain can be increased and their grip on reality can become tighter. The position of the third type does not doubt the fundamental hypotheticity of science either, but denies its relevance. Science has not to be judged primarily according to its epistemic values but through its practical advantages. According to this view, science is taken as a context of action that aims to change the world in order to meet human needs. Theories can be helpful in reaching this goal, but this is not necessarily so. Their hypothetical status is therefore of lesser importance.

A closer look reveals that the present debate about the significance of the hypothetical is not only controversial, but also somewhat confusing. The different positions cannot always be categorized in the suggested ways and show some overlap. Yet the major fundamental positions

remain visible. This is also exemplified by the case studies of this volume that refer to the present debate of the problem. Those positions that stress the practical dimension of science, like pragmatism in the follow-up of Charles Sanders Peirce or Bruno Latour's view, lead to a kind of downplay of the hypothetical aspect of scientific theories (third type). Hypotheses loose their immediate relevance for questions of truth and turn into productive anticipations of reality (Alfred Nordmann). If, however, one keeps to the epistemological attributes of theories, the hypothetical nature of science in general comes to the fore (second type). Two case studies discuss the retention of claims to the truth. The first deals with the relation between hypotheticity and scientific realism. The recognition of hypotheticity does not automatically exclude a realist point of view, provided it implies the possibility of approximate truth – on the contrary, such a view can even be based on hypotheticity if scientific realism is conceived as an empirical theory itself (Andreas Bartels). The other case study considers the metaphysics of nature as dependent on scientific hypotheses. One can understand metaphysics as being as hypothetical as the scientific theories from which it ultimately derives (Michael Esfeld). The esteem of hypotheticity can, however, also lead to a justification of the limited validity of scientific knowledge (first type). A further case study that can be counted as belonging to this position does not refer directly to the debate at present. The notion of a "closed theory" developed by Werner Heisenberg in the context of his quantum mechanics sees the reach of scientific theories as being limited through concepts and denies the possibility of a continuous progress of knowledge (Gregor Schiemann).

The different types of significance of the hypothetical in today's sciences have developed from specific historical constellations starting in the early modern era. The common origin is still present in the shared view that, in contrast to pre-modern conceptions from antiquity, hypothesis has a legitimate place and function in the process of knowledge. In Aristotelian science, which dominated the scene until the early modern period, the status of hypotheses is problematic. This is shown in a case study that deals with the development of astronomy of the middle-ages (Gad Freudenthal). One can even say that rejecting this aspect of Aristotelian science and incorporating hypothetical elements into the presuppositions and methods of modern science is among the decisive hallmarks of the Scientific Revolution (Ernan McMullin). That does not mean, of course, that this is enough for characterizing the fundamentals of modern science; suffice it to say that their changing relations to theology and religion as well as its new relevance for technology have to be taken into account.

Modern science's way of dealing with experience did not only imply the necessity of making room for hypotheses in science but also for limitations of scientific knowledge. There are reasons to suppose that even empiricist thinkers like Locke could not ground these limits exclusively in experience, but also in metaphysical presuppositions (Rainer Specht). All the new hypothetical elements notwithstanding, modern science still upheld truth as the goal of science in a largely comparable way as its predecessor. The second ideal type of significance of hypothesis that plays a role in the present debate originates from this historical constellation and is related to it with several different lines of development. One line is represented by the concept of induction that played a dominating role until deep into the 19th century (Laura Snyder; McMullin's section on Newton). Among the cases treated in this collection, Heinrich Hertz's hypothetico-deductivism provides an interesting further conception of the intricate and fragile balance of hypothesis and truth in science (Andreas Hüttemann).

In the 19th century, another process of change took place whose reverberations can still be noticed today in the first and third view on the significance of hypothesis. This was the growing conviction that all claims to final validity of scientific assertions about the world are hypothetical and with it all scientific theories. Instead of playing the role of useful and necessary conjectures on the way to truth that are finally overcome, hypotheses increasingly undermined the goal for which they were designed. In respect to considerations of validity, the traditional understanding of science began to change and was finally turned upside down: Instead of constituting irrefutable knowledge, science was increasingly seen as representing indemonstrable hypotheses. Science's immutable certainty was more and more disputed and taken over by refutability as a criterion of science; the trust in science's truth started to give way to a permanently effective suspicion of its possible failure. This development inaugurated a turn to a concept of science that eventually renounces any claim to truth and represents the first type of hypothesis as described above.

As in the Scientific Revolution, this process of change occurring in the 19th century has to be seen in the wider context of the changing social functions of science. Industrial development was based increasingly on scientifically produced technology (dye industry, electrical industry). Scientific results were now systematically incorporated into the production process of goods. Professional education in science and technology increasingly fell into the responsibility of the state which could in turn secure its influence by providing financial support for experimental research. State institutions had to watch over the implementation of large scale technology in science and industry. Developments like these, connected as they are with the applicational dimension of science, help to understand the course of increasing hypotheticity. In short, one can say that a key insight in the 19th century was the discovery that science can be socially useful even if epistemological questions, which had previously held priority, were left unanswered. Demand for the applicability of science overruled questions about its exact epistemic status.

The contributions of this volume do not deal with these more external relations of science to society but concentrate on the philosophical discussions that accompanied the developments described here and asked for the claim to truth. With the work of the mathematicians Carl G. J. Jacobi and Carl Neumann, the idea of axiomatic thought, to base knowledge of a field on self-evident assumptions, eroded "from above". The process of hypothesizing first principles likewise seized mathematics and mechanics (Helmut Pulte). The French philosopher of nature and science, Émile Boutroux, reached a hypothetical view of mathematics and science by making assumptions "from below", i. e. by admitting an irreducible variability and spontaneity on the micro-level of physical reality. The possibility of genuine novelty in nature as well as the hierarchical ordering of science into irreducible disciplines that build upon each other led to an insurmountable element of "contingency" in natural laws (Michael Heidelberger).

Both in Jacobi and Neumann as well as in Boutroux, one can discern considerations that come very close to the outlook on the foundations of mathematics and physics that was developed by Henri Poincaré at the turn to the 20th century. Poincaré's conventionalism can be regarded as one of the first and most effective formulations of a hypothetical conception of science. His epistemological analysis included a comprehensive classification of different meanings of hypothesis that are in use in mathematics (especially geometry), as well as in physics (Gerhard Heinzmann). To regard theories as hypotheses gives more possibilities in theory choice than if one remains wedded to a traditional conception that identifies science with truth and truth-seeking. One can decide only by convention between different theories of an object realm that are incompatible with each other but equally justified. This was one of the factors that made Poincaré keep to Galileo's conception of space-time against Albert Einstein's alternative (Scott Walter).

Poincaré's concept of hypothesis has interesting similarities with, but also differences to, Hans Vaihinger's concept of fiction. According to Vaihinger, a fiction is an idea that is blatantly false but nevertheless useful for dealing with reality. Together with hypotheses, fictions act as a basis for a pragmatic conception of science (Christophe Bouriau). To abstain from claims to truth concerning scientific assertions leads not only to a new appraisal of hypothesis, but also to a revaluation of the practical applications of science. The latter development is bound to advance the significance of hypothesis one step further and to completely cut the bond of hypothesis with its early modern origin.

Hypothesis in Early Modern Science

Ernan McMullin

Abstract:

My contention is that hypothesis gradually emerged from the shadows of natural inquiry in the period between Copernicus and Newton. Indeed, it might be argued that one perspicuous way to define the scientific revolution (an admittedly contentious term!) would be to detach just one theme, the conception of the sort of knowledge that constitutes the "science" of nature, and to note the profound shift in it that took place roughly between 1600 and 1700. Where the Aristotelian ideal of demonstration of a deductive sort from premises ultimately seen to be true in their own right could still claim wide authority among natural philosophers as the sixteenth century ended, it would have found little support among those pursuing systematic inquiry into the physical world a century later. And central to that profound change was the increasing visibility of hypothesis, both in the first-order role it played in the day-to-day activity of astronomers and natural philosophers and in the second-order way in which that role came to be discussed by them. What makes it worthwhile, I hope, to address in short space as broad a topic as this is to make good this claim.

Tracing the role of hypothesis in early modern science could prompt two quite different sorts of questions, what I will call first-order and second-order questions. One might investigate the methods, the strategies and the forms of reasoning implicit in the work of natural philosophers of the period from Copernicus to Newton with a view to determining to what extent and in what sort of contexts they had actually relied on hypothesis in their work. This first-order inquiry responds to a contemporary understanding of the two key terms in my title: Hypothesis in early modern science. But there is a second-order kind of inquiry which is also relevant: in their own reflective discussions of how systematic inquiry into the natural world should be carried on, what we might call their philosophy of science, what role did hypothesis play for the practitioners? I intend to ask both sorts of question and to note in some cases a striking dissonance between the answers. To do this necessitates, of course, careful attention to a third kind of question: