**THE INTERNATIONAL JOURNAL OF HUMANITIES & SOCIAL STUDIES**

# The Duhem-Quine Thesis vs. Crucial Experiments

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***Abstract***
*The Duhem-Quine thesis claims that experimentally refuting one theory through experiment can be always avoidable through some modifications of the auxiliary hypotheses involved. However, usually, the auxiliary hypotheses from an experimental setting are a lot more reliable than the main one being tested. So, it is not always possible, in a presence of the negative test result, to blame the auxiliary hypotheses to simply avoid refuting the main hypothesis being tested. Therefore, when reliable technological instruments form a significant part of the auxiliary hypotheses, some "crucial" tests can be effectively performed. After this "crucial" experiment, both parties involved in the debate reach at the same "satisficing" decision, and thus the scientific debate can end.*

## 1. Crucial Experiments

Can an alternative form of quantum mechanics such as the Bohmian models provide a potential opportunity for 'crucial' experiments to test the validity of (and possibly refute) the standard quantum mechanics in the future? With respect to this question, there are some points to make. First, according to physicists, quantum mechanics is the most successful theory ever in history of science (e.g. Leggett, 2002). There is no compelling reason to them to further test quantum mechanics at this moment. However, strictly speaking, quantum mechanics in its standard formulation has neither been very successful (or useful) and nor tested in the mesoscale domain. In this domain, the (standard) semi-classical models are still being actively developed in condensed matter physics nowadays. Some of the difficulties of quantum mechanics applied to the semiclassical approach are that quantum mechanics does not seem to converge directly to classical mechanics. Therefore, there seems to be a conceptual gap of applicable domain between the standard quantum and classical mechanics. That is, quantum mechanics is very successful in the microscopic domain and classical mechanics is well established in the macroscopic domain. Nonetheless, these two domains of application do not seem to overlap to each other and thus there seems to be a domain in which neither of the two theories is very successful in their applications. That is because physical variables in the two theories are apparently inconsistent or incommensurable to each other. The conceptual difficulty of the semi-classical approach within the standard framework seems to be originated from this apparent gap or hole of application in the mesoscale domain.

Second, the standard quantum mechanics and Bohmian quantum mechanics are mathematically equivalent to each other. Is it really then possible to make an observational difference between them in the first place? Again, however, although mathematically equivalent, the main issue is more than philosophical between the classical metaphysics of Bohmian quantum mechanics and the minimalistic positivism of the Copenhagen quantum mechanics. A difference can be made based on a technical aspect; Bohmian quantum mechanics provide a visually richer and intuitively better understanding of a dynamical process. The case for tunneling time calculation under the ontological interpretation is one great example here. With a continuous transition from quantum to classical domain, the Bohmian models can also make a more productive conceptual development on mesoscale dynamics under the hydrodynamical interpretation. Scientists can thereby pave a way to make a potential experimental test on the validity of Bohmian and the standard quantum mechanics in the domain.

Thirdly and more seriously, there exists a claim that a crucial experiment is logically impossible to achieve even in principle. The so-called Duhem-Quine thesis claims that experimentally refuting a main hypothesis in a theory can always be avoided and is, therefore, ultimately impossible. In order to test a particular hypothesis of a theory in question, an additional set of some auxiliary hypotheses are always required, usually in a context of the experiments being carried out. However, a main hypothesis could not be refuted by a negative test result through some modifications of auxiliary hypotheses involved in the experiment. Thus, the main hypothesis in question can always survive the experimental test and a scientific debate can continue no matter what the test outcome turns out to be.

However, the auxiliary hypotheses in an experimental setting are a lot more reliable than the main one being tested (Giere 1988). More specifically, when some widely shared (and thus reliable) technological instruments form a major part of the auxiliary hypotheses, it is not always possible, in a presence of the negative test result, to blame the auxiliary hypotheses to simply avoid refuting the main hypothesis being tested. Here, the modern technological instruments effectively act as the shared background knowledge (Giere 1988; Hacking 1983) by both parties involved in a scientific debate. Afterwards, the scientific debate can be effectively ended.[1]

For example, while some physicists may have mathematical simplicity as their highest priority, as in the standard quantum mechanics, others prioritize cognitive advantages such as visual, pictorial, and intuitive virtues, as in Bohmian quantum mechanics. As time goes on, these separate groups lead to two different research traditions, following their own priorities of available options. Eventually, they may engage in a scientific debate. However, the debate does not necessarily have to continue indefinitely. With some reliable technological instruments, "crucial" tests favoring one type of research tradition rather than the other can be effectively designed and performed. This is possible because some instruments from a widely shared (and thus reliable) technology could give rise to such a set of experiments. After the experiment, the both parties involved can reach at the same 'satisficing' decision, the 'satisficed' scientists could now form a widespread satisfactory consensus in choosing one model rather than the other. These 'crucial experiments' can thus serve as more or less clear-cut experimental evidence, favoring one side rather than the other in a scientific dispute between two radically different traditions of research. This whole decision-making process and its related aftermath, once again as a part of the 'satisficing strategy,' can end a scientific dispute (Giere, 1988).

## 2. The Duhem-Quine Thesis

Between the Bohmian interpretations and the Copenhagen minimalist one, is there any way to have some possible observational differences? Although mathematically equivalent with the standard quantum mechanics, Bohmian quantum mechanics provides an intuitively rich understanding of a dynamical process with a continuous transition from quantum to classical domain, and thus can make productive conceptual developments on mesoscale dynamics. As discussed in the sections for tunneling time calculations under the ontological interpretation and for mesoscale dynamical simulations under the hydrodynamical interpretation, this intuitive advantage of a quantum dynamical process can lead to a definite outcome in the Bohmian interpretations, but not in the standard quantum mechanics. In principle, scientists can thereby make an experimental test of the validity of the standard quantum mechanics in relation to other interpretations of quantum mechanics such as the ones by Bohm. Consequently, at stake are more than just the two different philosophical views, the classical metaphysics versus the minimalistic positivism. There are still several open issues, however: "It remains unclear whether or not a convincing test is possible in this area. […] So much is at stake - two radically different ontologies or worldviews - that the dominant school would more likely claim to have "learned" how to calculate (in this case) than to grant reality to the microstructure that still remains not directly observable "(Cushing 1994, p.55).

Here Cushing seems to invoke the famous Duhem-Quine thesis - the impossibility of a crucial experiment between two competing theories. Pierre Duhem (1861-1916) was a French physicist, historian, and philosopher. His philosophical methodology and beliefs had an influence on the positivism in the late 19th century and then on the logical empiricism of the Vienna Circle in the early 20th century. He was later introduced in English speaking countries in *Two Dogmas of Empiricism* by philosopher Willard Quine in 1953. When Quine mentioned Duhem in the book to explicitly construct Duhem-Quine thesis as it is often called now, it was stated as follows. "A conflict with experience at the periphery occasions readjustments in the interior of the field" (Quine 1953, p.42). But, "any statement can be held true come what may, if we make drastic enough adjustments elsewhere in the system" (p.43). It is often pointed out however that the version by Quine was not exactly the same as the original claim by Duhem himself. Duhem seemed to have a somewhat weaker version of it as follows. "The only thing the experiment teaches us is that, among all the propositions used to predict the phenomenon and to verify that it has not been produced, there is at least one error; but where the error lies is just what the experiment does not tell us" (Duhem 1914, p.281; 1954, p.185). Nevertheless, there seems to be a general consensus that Duhem's original criticisms of crucial experiments were still well carried on in the version by Quine and later philosophers.

A modern version of the Duhem-Quine thesis is often cited to be a philosophical and logical objection to the possibility of a crucial experiment as follows: the theory under examination may always not be refuted even in the presence of apparently negative experimental outcomes when it simply takes suitable auxiliary modifications usually in a context of an experimental setting.[2] This Duhem-Quine thesis has become one of the foundations for a holistic attitude toward scientific knowledge. Suppose that H represents the hypothesis being examined, A the auxiliary hypotheses in an experimental setting, and O the predicted outcomes. Since the total package of H and A implies O, the negation of O only means either H or A is false, logically not necessarily H to be false. Therefore, a falsification of H under the negative evidence O can always be avoided and H can survive

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[1] To be historically more conscious in explaining the crucial experiment, it should be pointed out that the crucialness of the experiment often becomes evident only in hindsight; it is only in hindsight that a certain experiment turns out to be 'crucial,' playing the role of adjudicating between competing theories. This "hindsight" aspect of the crucial experiment will again be mentioned in the last chapter as a criticism on Leggett's program in which a set of experiments can be potentially 'crucial' on checking the limits on the validity of quantum mechanics . On the other hand, in the Kuhnian sense, the crucial experiment is rather more important in generating crises which end up leading to a new direction of research by, for example, recognizing the existence of previously unknown phenomena etc. So, the particular way of understanding the crucial experiment as in this chapter (i.e. as a way of adjudicating between already existing different theories) is rarely of big concern to historians. Most of them tend to see the crucial experiment in the light of the Kuhnian sense which is a way of framing away Duhem-Quine thesis.

[2] This is from the Standford Encyclopedia of Philosophy on Pierre Duhem by Roger Ariew (http://plato.stanford.edu/entries/duhem/).

the negative outcomes, by blaming A to be false. This situation suggests the impossibility of any experimental tests in refuting a theory.[3]

This formulation of the Duhem-Quine thesis above obviously puts H and A on the same logical ground. However, Ronald Giere (1988) claims that this same logical grounding is not justified if A is believed to be a part of commonly shared and thus reliable technology. Therefore, blaming A to be false to save H under the negative experimental outcome as in the Duhem-Quine type situation is not always a possible option, given the commonly shared acceptance of A by both parties involved in a scientific debate. Here, Giere seems to raise an important issue of 'background knowledge' in science (Giere 1988, p.140) as follows;

At least some background knowledge is better thought of as embodied knowledge. It is embodied in technology used in performing experiments. The cyclotron, for example, was designed with the intention of using it to accelerate protons (among other things). The design may therefore be thought of as embodying some of our knowledge about protons, such as their charge and mass. […] Now our knowledge of how to produce those [proton] beams has been built into the design of modern cyclotrons and their accompanying instrumentation. […] Thus, some of what we learn today becomes embodied in the research tools of tomorrow.

### 3. Satisficing Strategy

As seen above, Giere claims "scientists' knowledge of the technology used in experimentation is far more reliable than their knowledge of the subject matter of their experiments"(Giere 1988, p.139).[4] So, for example, protons or electrons used in a cyclotron research facility are not nearly as questionable or disputed as the subject matters of physicists' research, say, the detailed structure of the nucleus. More specifically, nuclear physicists in a cyclotron facility consider protons as reliable entities in their research for a nucleus study. They work with the understanding that protons with known properties of mass, charge, and momentum move around magnets, go down beam pipes, and enter into a cyclotron. The properties of protons are not disputed in any respect whatsoever in their research. All nuclear physicists can casually agree on calculating a proton's specific orbit size and its velocity in a given problem of their research while, at the same time, making alarm systems for safety measures from the calculated velocity of the proton in the orbit. These particles have become essential 'research tools' for investigating the structure of the various atomic nuclei, for example. Consequently, in most cases, the operation of 'off-the-shelf' experimental instruments is exceedingly well understood compared to the subject matters being tested.

Ian Hacking (1983) also argues for the epistemological importance of experiments. He denies that the experiments being performed are always already informed by the theory being tested in the first place (i.e. theory-ladeness). Theory-ladenness claims refuting or testing a theory in question from experiments is impossible because the theory and the experiments are already inseparable before testing. However, Hacking argues that a theory being tested is not necessarily dependent on and can be different from the theories involved with experiments. Both Giere and Hacking share many similar ideas on experimental practices; "the vast majority of experimental physicists are realists about some theoretical entities, namely the ones they use" (Hacking 1983, p.262). However, "experimenting on an entity does not commit you to believing that it exists. Only manipulating an entity, in order to experiment on something else, needs do that" (p.263). Hacking then continues (p.265),

We are completely convinced of the reality of electrons when we regularly set out to build – and often enough succeed in building – new kinds of device that use various well-understood causal properties of electrons to interfere in other more hypothetical parts of nature.

Hacking's view that "engineering, not theorizing, is the best proof of scientific realism about entities" (Hacking 1983, p.274) is more evident with his well-known case study on PEGGY II. Hacking (1983, 1982) argues that the use of PEGGY II to test the Weinberg-Salam model of Grand Unified Theory was made possible since scientists now know 'reliably' (according to Giere's terminology) about the behavior and properties of electrons. PEGGY II's basic idea began by chance with the fact that a crystalline semi-conductor called gallium arsenide (GaAs) emits lots of linearly polarized electrons under some right conditions. This came from an unrelated experimental investigation in condensed matter physics, an independent research area from elementary particle physics. Nevertheless, the semi-conducting device developed by condensed matter physics is applicable in testing a Grand Unified Theory. Even in condensed matter physics, the properties and functions of the actual GaAs used in PEGGY II are not well-understood by quantum theory of crystals (although very well-known in practice), and there is no guarantee that the bits and pieces in the experimental setting would fit nicely together to perform the entire package of experiment. Nonetheless, testing a Grand Unified Theory was made possible by technological instruments including, for example, 'research tools' and GaAs devices, all developed and established in other areas of research. This can avoid the complications stated by the Duhem-Quine thesis. In PEGGY II experiment, for example, some areas of condensed matter physics, device engineering, and elementary particle physics are all, in practice, indisputable enough to perform a particular kind of crucial experiment.

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[3] Bohmian theories are more than philosophical interpretations and can thus be subjected to an experimental test. Their current applications are usually made in the domain of mesoscale region while the standard quantum mechanics is not yet well developed for the domain. As physicist Leggett argues in the following chapter, the limits on the validity of the standard quantum mechanics in this domain is actively being investigated in condensed matter physics nowadays. Consequently, to Leggett, this region seems to be a future battle-field to test the standard quantum mechanics and some other forms of quantum mechanics such as GRW theory. However, he does not consider Bohmian quantum mechanics as an alternative theory of quantum mechanics in his program to test the limits of the validity on quantum mechanics.

[4] The reliability in Giere's claim seems to mean something like being 'shared by both parties involved in the debate' while the subject matter of the debate is disputed by both parties.

Giere then introduces the notion of a 'satisficing strategy' (Giere 1988, p.157). Here Giere draws from Herbert Simon's work on administrative men "with a very restricted set of options and possible states of the world" (p.158) in the context of business administration (Simon 1945, 1957, 1979, 1983; March and Simon 1958). Simon is concerned with instrumental rationality of human actions directed toward reaching specific goals. The administrative agents "operate under conditions of what [Simon] came to call bounded rationality"(p.158). Although "bounded by limitations on their abilities to gather, store, and process information about their immediate decision-making context,"(p.158) they may be able to rank-order all possible outcomes of the decision-making processes, and can still "distinguish their decision-making outcomes that are satisfactory from those which are not" (p.158). In Giere's view, a satisficing strategy is just one particular type of natural human cognitive activity of decision-making processes, under some heavily uncertain circumstances with substantial unknown outcomes and risk factors involved. The most satisfying decision under the circumstance can be made possible based on the prioritized (and ranked) list of options with a particular 'satisfaction level', or 'aspiration level' at hand. In the case of more than one satisfactory option, the agents can raise their satisfaction level until only one option remains satisfactory. But, if there are no satisfactory options, the agents can lower their satisfaction level until some option becomes satisfactory. Or, the agents may proceed to seek new options, without lowering their satisfaction level. Thus, the 'boundedly rational' agents can make decisions as 'satisficers.'

According to Giere, many aspects of human cognitive action seem to work within a category of this bounded rationality. Here, something like 'educated guess' and 'intuitive preference' can be all incorporated when people distinguish their own satisfactory outcomes from unsatisfactory ones. This could explain why some people as compared to others choose to exercise a totally different set of decision-making options even in an almost identical situation. So, some options with lower ranking orders than 'a satisfaction level' are not simply employed while other higher ranking options are actively employed in their decision makings.

To those scientists who prefer to gain an intuitive or cognitive advantage from various forms of representation, constructing a metaphysically heavier model may not be a great concern.[5] They have some lower priority for the metaphysical burdens among their selection options. Also, they may care less about mathematical simplicity, elegance or purity of their models. At some point in their ranked options, some lower priority options are not satisfying to their research needs as their possible selection options. Naturally, however, some others may have radically different ranking orders among their selection options.

Thus, while some physicists may give the highest priority to mathematical simplicity, others most-highly prioritize to cognitive advantages such as visual, pictorial, and intuitive virtues. In particular, physicists practicing the standard-text-book-based quantum mechanics do not want to add any more forms of representative devices than a pre-existing (bare-minimal) mathematical structure into their quantum mechanics, because they believed introducing a concept such as a particle's trajectory would automatically jeopardize the whole conceptual consistency of quantum mechanics, since doing so would violate the uncertainly principle. Or, some others may simply say that they choose not to exercise any heavier metaphysical commitment even if it is possible to introduce the trajectory.

However, to those who practice the Bohmian quantum mechanics with the various types of representative devices inside, a particle's trajectory becomes an essential part of rich visual illustrations and ontological metaphors. The Bohmian researchers prioritize various forms of representative devices that can powerfully motivate their visual intuitions in their research. They, at the same time, have distinctively lower priorities in their research options for mathematical simplicity and purity. To them, the semi-classical models from the standard quantum mechanics have an intrinsic and conceptual arbitrariness in the ways they mix classical and quantum mechanical variables. In fact, the semi-classical models often become less satisfactory on a smaller physical scale and there is no way to estimate correction-errors involved in the calculations due to the initial arbitrariness. In other words, to them, those hybrid models lack internal flexibility of adjusting their domains of application, for example, through some kind of free parameters to easily control the models from outside. Once constructed, it is impossible to adjust the way in which classical and quantum variables are mixed.

In a course of scientific endeavor, these research groups can actively pursue their own priorities in their decision options. Based on their radically different research options, as time goes on, these decision-making processes can lead to two different paths of the research tradition, following their own prioritized available options. For example, Bohmian quantum mechanics forms a separate research tradition in contrast with the standard quantum mechanics. Eventually, in the future, they can engage in a scientific debate. Currently, however, these research traditions belong to largely three different and separate communities, that is, the traditional condensed matter physics community, quantum chemistry, and finally electrical engineering communities. These three non-interacting communities thus do not yet engage in any type of quantum mechanical debate. Nonetheless, emerging multi and interdisciplinary research environment in nano-science and -technology may prove otherwise in the future. This environment involves active scientific and engineering developments on understanding mesoscale phenomena. Consequently, the semi-classical models from the standard quantum mechanics of traditional physics and the Bohmian models of quantum chemistry and electrical engineering can meet together in this new research environment, forming a possible future scientific debate on quantum

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[5] Physicists often criticize Bohm's realism and determinism in his ontological quantum mechanics as something 'heavily metaphysical' that is however destined to make no observational difference whatsoever. To them, Bohm's heavy metaphysical commitment is simply unnecessary in the (minimalistic) standard quantum mechanics. However, to others, it is Bohm's metaphysics that provides intuitive and visual dynamical explanations. In the hydrodynamical quantum mechanics, Bohm's determinism (not necessarily realism) leads to a better numerical scheme of visual trajectories for chemists and electrical engineers. They may not directly reflect on their metaphysical commitment as much as physicists because they are working in larger scale systems by a physicist's standard in developing a feasible numerical approach of quantum phenomena. However, the chemists and engineers will still admit that it is Bohm's hydrodynamic determinism, a metaphysical component of Bohm's hydrodynamical scheme that makes the trajectory scheme possible for their research.

mechanics. Leggett is one of the rare physicists who contemplates testing the limits of (the standard) quantum mechanics and thus casts a doubt on its validity in the mesoscale region (e.g. Leggett 2002).

However, the debate does not necessarily continue indefinitely as in the Duhem-Quine situation. Scientists from different research groups can agree on some experiments which could potentially test or refute their own theories. This is possible because some instruments from a widely shared (and thus reliable) technology could give rise to such a set of experiments. These “crucial experiments” can serve as more or less clear-cut experimental evidence, favoring one side rather than the other in a scientific dispute between two radically different traditions of research. After the “crucial” experiment, the both parties involved reach at the same ‘satisficing’ decision, the ‘satisficed’ scientists could form a widespread satisfactory consensus in choosing one model rather than the other. This whole decision-making process and its related aftermath, once again as a part of the ‘satisficing strategy’, thus, can end a scientific dispute (Giere, 1988).

## 4. Conclusion

In short, with all of these radically different selection options and satisfaction levels available to the competing research traditions, the satisficing strategy combined with reliable modern technology can eventually lead to a ‘crucial experiment,’ providing a common ground to potentially settle a scientific dispute. This satisficing strategy, thus, greatly weakens the Duhem-Quine account of continuing disputes.

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