THE INTERNATIONAL JOURNAL OF HUMANITIES & SOCIAL STUDIES

Crucial Experiments in History of Science

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Abstract:
In history of science, some cases support for the existence of crucial experiments. These experiments rely on new technological instruments to effectively end their scientific debates.

1. Introduction

In history of science, some cases support the existence of some crucial experiments. These experiments were based on the technological instruments reliably shared by the both parties involved in a scientific debate and helped overcome a situation of continuing debate as in the Duhem-Quine thesis. For example, radio antenna technology proved to be crucial in detecting the cosmic microwave background radiation that established the big bang theory of the Universe, consequently defeating the steady state theory (e.g. Brush 1992, 1993). A set of experiments similarly turned out to be crucial in effectively ending the debates and successfully establishing for the relativistic nucleus model (Giere 1988), and also for the Grand Unification Theory (Hacking 1983).

2. Ether

The 19th-century 'ether', however, seems to be a case for the Duhem-Quine type of situation (thus a case against the argument made above), since ether survived a series of 'crucial' experiments designed to refute it. People stick to the idea of ether by simply changing some auxiliary hypotheses involved in the experiments, as in the Duhem-Quine thesis. However, it should be emphasized that *ether as a concept and illustration* still played a major role in the development of the 19th century electro-magnetic theory. Based on their ether model, people developed complex conjectures about matter and space, and made mechanical and illustrative devices to further elaborate their ideas. (e.g. Dear 2006. See Chapter 5 on Dynamical Explanation: The Aether and Victorian Machines.) Some even went on to speculate that the ether model might provide not only the connection between mind and body, but also between this and the unseen world (Powers 1987, p.241). These aspects of ether will be more clearly discussed below as an example showing the importance of visual representations (as in the Bohmian quantum trajectory method).[1]

As the agency of mediating (electric) forces between electrified bodies across distances of space, ether was understood either as a continuum or as discrete particles of the contiguous elements existing in the space. This ether model played a major role in developing and evaluating the 19th century electromagnetic theory (Harman, 1983). According to Harman, Maxwell advanced from 'an imagery of physical geometry' to a mechanical point of view in that the motion of one part of the ether communicated to another by some dynamical processes. His ether as a magneto-electric medium was elastic and cellular, each cell consisting of a honeycomb-like vertex surrounded by a layer of idle-wheel particles. Maxwell's elastic ether model "resulted in the unexpected unification of optics and electromagnetism"(Harman, 1983, p.92). He therefore concluded that light consisted of the transverse undulations of the same medium which was the cause of electric and magnetic phenomena. As time went on, "his confidence in the physical existence of the ether was strengthened" (p.93) and the heuristic value of the idle-wheel model became more obvious to him. George Fitzgerald also developed a theory in which ether and matter were represented by vortex motions in a universal plenum. This mechanical ether model was composed of wheels and rubber bands to provide a mechanical illustration. Similarly, for example, Joseph Larmor also proposed that the ether could be represented as a homogeneous fluid medium. Although strictly illustrative and heuristic, Larmor's physical model of ether was at least a working representation of ether. Eventually, Hertz declared, "the detection of electromagnetic waves would confirm that there was a substance pervading air that was subject to electromagnetic polarization, and would thus confirm the theory of electromagnetic ether, the essential feature of Maxwell's field theory" (p.108). Hertz thus believed in the "identity of light, radiant heat, and electromagnetic wave-motion"(p.109).

At this stage, Maxwell suggested that the experimental detection of the earth's motion through the ether could be possible by measuring the variation in the velocity of light in different directions. Albert Michelson with Edward Morley then tried an experimental test of the variation in the velocity of light and showed that the earth's motion relative to the ether was undetectable. However, they concluded that the ether was not stationary and that Sokes' dragging ether should be preferred. Alternatively, in 1892, Lorentz (also independently Fitzgerald) suggested that the interferometer in the arms of Michelson-Morley experiment

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[1] Like ether in 19th century electromagnetism, the quantum trajectory in the Bohmian hydrodynamic quantum mechanics has an analogous role as an illustrative and metaphoric entity.

contracted in the direction of the earth's motion in the stationary (not dragging) ether. The famous 'contraction' was introduced to compensate for the effects to be expected by the motion of the earth through the stationary ether.

As seen above, ether was therefore declared to survive a series of crucial experiments. Once people believed that ether was established, it could avoid being refuted through changes in its related auxiliary hypotheses as in the Duhem-Quine thesis. However, Maxwell understood his electromagnetic waves as the propagation in ether. Hertz confirmed the existence of radio waves in terms of the ether model. Michelson and Morley also could come up with their interferometric experiments in an effort to test the ether, and then interpret their experimental outcomes in a modified ether model despite the fact that the experiments failed to detect ether drift. Giere responds to this as follows (Giere 1988, p.107);

Whether the ether exists or not, there are many respects in which electromagnetic radiation is like a disturbance in an ether. Ether theories are thus, in this sense, approximations. The fact that there is no ether is one very important respect in which there fails to be a strong similarity between ether models and the world. That failure is a good basis for rejecting ether models, but not for denying all realistically understood claims about similarities between ether models and the world.

Giere argues the ether was only a provisionally sound research tool. Later on, doubts occurred, and eventually the doubts turned out to be strongly legitimate enough to revise scientists' beliefs on its existence. The drift experiment by Michelson and Morley turned out to be crucial enough to reject the idea of ether altogether. Finally, electromagnetic theory of the 19th century was reinterpreted, and a new theory of mechanics (i.e. a special theory of relativity) emerged without ether involved. Ether simply became unnecessary in a mechanical theory of nature. But, the various outcomes out of the provisionally sound research tool still persisted and remained to be productive in the later developments. In that sense, ether as a concept and illustration played a major role in the development of the 19th century electro-magnetic theory. Therefore, although the ether can be a case for the Duhem-Quine thesis, at the same time, this seems to show the importance of scientific representations based on visual illustrations and intuitive metaphors.

Jordi Cat (2001) also emphasizes the essential role played by some intuitive and pictorial devices in the development of the 19th century electro-magnetic theory, and claims that the cognitive importance of illustrations and metaphors cannot be dismissed as merely an educational or an ornamental tool. They play a central role in research developments, and also in technical writings and addresses to professional (and the general) audiences. According to Cat, Maxwell's visual research tradition eventually gave rise to a series of experimental activities to test the electro-magnetic theory itself. In Maxwell's mechanical model of ether, in particular, metaphors and illustrations served as mediators between mathematical symbolism and physical phenomena. Electromagnetic contiguous action occurs in the so-called molecular-vortex model or the idle-wheels model of the ether as a connected system.[2] This idea of contiguous action in the model, however, does not seem to correspond to any real physical situation. It was usually provided by Maxwell's own imagination. Also, Maxwell's assertions, such as 'the particles are hard, spherical and elastic' in his 'billiard-ball model' of gases, are only metaphorical or illustrative. "Typically, such models include representations that are either geometrical or mechanical, either visual or muscular, depending on the properties selected" (Cat 2001, p.410). As a consequence, the dichotomy between realism and instrumentalism proves inadequate for making sense of Maxwell's position.

3. Bohmian Quantum Mechanics

In the visual image tradition of the Bohmian ontological interpretation, the continuity of theoretical practice has been motivated by prioritizing 'visual corpuscular illustrations and metaphors', rather than by 'mathematical simplicity and purity.' On the other hand, in the hydrodynamical interpretation where particle ontology disappears, the quantum trajectories of probability density are a guiding light for the entire hydrodynamic scheme, providing a visual direction of the propagation of the fluid in such a way that the actual locations of the trajectories are used to calculate the propagation of the trajectories some time later. The method thus has greater computational and cognitive advantages by visually illustrating how the quantum fluid elements are propagated through real space and time. It thus strongly appeals to some of the professional audience, who prioritizes visual illustrations.

However, the quantum trajectory itself may not to be taken literal or empirical. It is nonetheless a powerful, imaginary, computational tool. As Alisa Bokulich (2008) emphasizes in her discussions for the advantages of semi-classical models, the Bohmian trajectory method can be effective "investigative," "calculational," and "interpretative" tools (Bokulich, 2008, p.112). To those chemists who use the Bohmian trajectory model, it is an effective and pragmatic middle path to accommodate both quantum and classical physics, simultaneously, offering visual and intuitive advantages. With particle ontology and visual corpuscular trajectory, the Bohmian ontological interpretation can extend classical causal intuition into the non-classical domains. In the hydrodynamical interpretation, the visual and intuitive advantages from a probability density trajectory translate into a (known) practical numerical scheme through the use of computational fluid dynamics. Eventually, the method may be able to provide a potential opportunity for crucial experiments to test (and refute) the standard quantum mechanics in the future, with some help from modern technological instruments.

4. Nucleus Model

Emphasizing evidence from the history of science, Giere himself provides his own case study based on a satisficing model of scientific judgment (Giere 1988, p.179-226). It is about models and experiments in understanding an atomic nucleus and its internal dynamics using theoretical concepts of nuclear interactions, quantum theory, quantum electrodynamics, special theory of relativity, and quantum chromodynamics, etc.

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[2] A visual illustration of the model can be found in Maxwell's paper, for example, 'On Physical Lines of Force. Part I', Philosophical Magazine, vol. XXI, April and May 1861.

The major task of understanding the structure of an atomic nucleus is to determine the combined total potential of all the individual particles in a particular type of nucleus. The simplest nucleus model is the one that ignores all interactions among nucleons in the nucleus, the so-called ‘impulse approximation.’ Up to around 1980, the so-called standard models were based on this impulse approximation together with the non-relativistic Schrödinger equation for two free nucleons. Physicists call them ‘the Schrödinger approach’ or ‘the non-relativistic approach’ which include individual models such as DWIA (distorted wave impulse approximation), the KMT (Kerman-McManus-Thaler) model, and BHF (Brueckner-Hartree-Fock) theory etc.

However, the model of the nucleus should not be based on the non-relativistic Schrödinger equation, but on a relativistic version of the Schrödinger equation called the Dirac equation. Nevertheless, the prevailing attitude among nuclear physicists before 1980 was that relativistic models were not necessary because they do not make any observational difference at the level of experiments. To a majority of nuclear physicists, thus, developing a relativistic nuclear model was not one of their highly ranked selection options in their research. On the other hand, there were a small number of people who had relatively higher priorities for investigating for such a relativistic model, and their satisfaction level was also higher than just fine-tuning and modifying the available non-relativistic model.

In the mean time, in 1977, several research groups working at the Los Alamos Meson Physics Facility (LAMPF), which has a medium-high-energy proton accelerator at 800 MeV, began collecting data using a newly constructed polarized ion source together with a new high-resolution spectrometer for measuring the energy of scattered protons from elastic proton-nucleus interactions. In 1979, the first polarization data, for 800 MeV protons on a calcium-40 target nucleus, failed to agree with any standard Schrödinger models. In 1981, another polarization data at 500 MeV, for calcium-40 and several other target nuclei, exhibited the same sort of divergence from the standard calculations. At the same time, the new polarimeter made it possible to measure a second spin variable called ‘the spin rotation parameter.’ The first published measurement of the spin rotation parameter for calcium-40 at 500 MeV also showed considerable deviation or “a serious lack of agreement quantitatively” from standard predictions. Finally, in mid-1980s, the new data that failed to fit the prevailing non-relativistic Schrödinger models were very quickly shown to fit available preliminary Dirac models, especially the one by Bunny Clark and her collaborators in 1983. These Dirac models gave a substantially better fit than any corresponding non-relativistic Schrödinger models. However, this new model fitting still did not yet convince many people of the Dirac approach.

Clark and her collaborators then started to use the Dirac model to ‘predict’ the free parameters in the model using only the cross-sections and the polarization. Their calculations were first presented publicly at a conference in October 1982. Since the beginning of 1983 dozens of articles on Dirac approaches to nuclear physics have appeared. Virtually every one of those papers cited the work by Clark *et al*. Theoretical nuclear physicists started to develop a relativistic version of the impulse approximation, calculating the total potential of a nucleus using the Dirac equation. By 1985, whole conferences were organized to discuss the latest theoretical and experimental findings relevant to the development of these models.

In retrospect, how did individual scientists make the decision to devote their efforts to the development of relativistic Dirac models of nuclear interactions? Here, in this case study, the answer seems to have something to do with the ‘crucial experiments’ at LAMPF with new instruments. The new instruments produced the new data that failed to fit the prevailing Schrödinger models, but which were very quickly shown to fit the preliminary Dirac models. Then, to a majority of nuclear physicists, developing a relativistic nuclear model became one of their highly ranked selection options in their research. Nuclear physicists then started to put higher priorities on investigating for such a relativistic model, and their satisfaction level was also higher than just fine-tuning and modifying the available non-relativistic models.

5. Geology in the 60s

A crucial experiment also seems to be evident in geological developments in the 1960s. At the turn of the last century, earth scientists believed the earth had cooled, contracted and solidified from a much warmer body of a molten sphere. However, this ‘contraction model’ came to be abandoned and then the so-called ‘drift model’ was widely accepted by earth scientists, when in 1966 magnetic sounding across the Pacific-Antarctic Ridge and surrounding sea floor sediments clearly showed evidence of magnetic patterns of reversals predicted by the drift model. Since then, “the impact on the earth sciences community was swift and complete. Within a year just about everyone with professional competent knowledge of the situation accepted some sorts of drift hypothesis” (Giere 1988, p.393). The reliable magnetic sounding technology was thus ‘crucial’ enough to avoid a complication of the Duhem-Quine thesis.

6. The Big Bang Cosmology

For another case of a ‘crucial’ experiment, there was the discovery of the cosmic microwave background radiation (CMBR) in the 1960s. In the middle of the twentieth century, with experimental equipment sensitive enough, the two competing cosmologies emerged; one is called the big bang cosmology, and the other is called the steady state cosmology. During this moment, for a highly sensitive radio astronomy study with a powerful radio antenna, Penzias and Wilson at Bell Labs needed to get rid of the alleged ‘microwave noise’ persistent from their antenna, but in vain. After talking to Dicke and Peebles at Princeton, Penzias and Wilson noticed that they were detecting the CMBR, the afterglow of the big bang, by measuring the temperature of space (about 3.5 Kelvin degree at the time). The groups from Bell Labs and Princeton announced the discovery in May 1965, and published together in the July 1 1965 issue of *Astrophysical Journal*. Then, the whole astronomy community rushed to accept the big bang model. The only available ‘satisficing option’ in the decision making process was to accept the big-bang model which fits the observation much better than the steady state model. Scientists simply have a strong interest in being ‘satisficing’ at the right time. Brush (1992) wrote (p.70),

By the late 1970s nearly all the original supporters of the steady state model had explicitly abandoned it or simply stopped publishing on the subject. [...] The discovery of the cosmic microwave background, […], convinced most steady staters that their theory was no longer worth pursuing. It had been tried and found wanting.
Brush (1992) then adds (p.62),
The steady state model of the universe predicted no such radiation and could not plausibly account for it. Thus, for the first time, hypotheses about the origin of the cosmos had faced an empirical test that left a winner and a loser. Rarely do theories stand or fall on the outcome of a single test. This time, however, opinion shifted almost overnight. Within a few years, most cosmologists had either adopted the big bang theory or ceased publishing in the field.
As late as the 1980s and the 90s, Hoyle, the only major holdout, still tried to revive a 'modified' steady state model, giving an alternative explanation for the origin of the CMBR within a frame of the steady state theory. He suggested that some iron needle-shaped dust particles, called the 'whiskers', in our own galaxy could produce the microwave background radiation, mimicking the essential features of the CMBR (Arp et al.). However, a feasible modification just to survive a 'crucial' experiment is often considered to be an *ad hoc* modification, and thus neither relevant nor satisficing to most of the scientists involved (Brush, 1992). In Giere's terms, it is not a 'satisficing option,' especially after a decision has already been made, since "a satisficer would ask for no more" (Giere 1988, p.394). It already became irrelevant whether there were logically possible steady state models that could yield the observation of the CMBR.

7. Conclusion

As seen so far, in a very similar pattern of (social) decision-making processes at the end of scientific disputes, something called a 'crucial' experiment can be noticed in the cases. After a 'crucial' experiment, scientists can form a widespread consensus in choosing one model rather than the other. Once they decide one rather the other with some 'satisfaction,' an alternative feasible attempt from the other side just to survive the crucial experiment simply becomes irrelevant or *ad hoc*. The crucial experiment is just crucial enough to avoid the Duhem-Quine complications.

8. References

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