SCIENTIFIC INSTRUMENTS AND EPISTEMOLOGY ENGINES

Abstract: *This article outlines the gradually changing attitude towards instruments and materials in the philosophy and historiography of science and confronts contemporary revaluations of the material culture of science with Hans-Jörg Rheinberger's concept of an experimental system and Don Ihde's notion of an epistemology engine.*

Keywords: *material culture of science; scientific instruments; epistemology engines; experimental systems*

Vědecké přístroje a epistemologické stroje

Abstrakt: *Článek popisuje postupnou změnu postoje vůči přístrojům a materiálům ve filosofii a historiografii vědy a konfrontuje současné snahy o přehodnocení materiální kultury vědy s koncepcí experimentálních systémů Hanse-Jörga Rheinbergera a epistemologických strojů Dona Ihde.*

Klíčová slova: *materiální kultura vědy; vědecké přístroje; epistemologické stroje; experimentální systémy*

TOMÁŠ DVOŘÁK
Kabinet pro studium vědy, techniky a společnosti
Filosofický ústav AV ČR, v.v.i., Jilská 1, 11000 Praha 1
email / tomdvorak@flu.cas.cz

Scientific instruments

In 2011, Steven Shapin and Simon Schaffer wrote a new introduction to the reprint of their now classic *Leviathan and the Air-Pump*. Their aim was to map the situation in the field of the historiography of science around 1985, when the book was first published, and to outline the development of the field in subsequent decades through a detailed analysis of the reception of their book. On the opening page, they indicate two technologies that were essential to their work: first, obviously the air-pump and its role in the making of knowledge in the seventeenth century, and second, the typewriter (and the related forms of science communication of the day) that they themselves used in their knowledge-making process. Although they suggest that the typewriter presented certain possibilities and limits that influenced the nature of knowledge as well as the forms of intellectual and social order that they did not acknowledge at the time, they do not pursue its analysis. The typewriter figures in their introduction as an element that creates a historical distance (this is in the second half of the 1980s, when the typewriter began to give way to digital forms of text processing), marking an interval in time, and that situates their book as a historical and in a sense even a surpassed chapter in our body of knowledge: "it would be wonderful to inhabit an academic world in which there would be no call for a new edition of a work of empirical history produced by members of a previous generation".[1] The use of the estrangement effect of old technology to stress the historicity of a certain kind of knowledge does not necessarily make the logic, economy and politics of the development of knowledge identical to the logic, economy and politics of the development of technology. It does, however, point out the need to pay attention to the relationships and interdependencies between the material conditions of knowledge and the nature of the knowledge produced under those conditions.

Shapin and Schaffer managed to describe the emergence of a new style of reasoning through the ties between the material, literary and social technologies of the seventeenth century. Although some of their conclusions were rightfully disputed, their form of "ethnographic" case study has become

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[1] Steven SHAPIN – Simon SCHAFFER, "Up for Air: *Leviathan and the Air-Pump* a Generation On." in: Steven SHAPIN – Simon SCHAFFER, *Leviathan and the Air-Pump. Hobbes, Boyle, and the Experimental Life*. Princeton: Princeton University Press 2011, p. xlx (xi–xlx).

very influential in the historiography of science focusing on experimental practices. The "practical turn", as this tendency of the 1980s is sometimes labelled, led to an emphasis on those aspects of science and knowledge that were previously ignored because they were considered epistemologically irrelevant, such as the instrumental equipment and materials used or developed in research, know-how and professional skills, local norms and standards, financial sources and the organisation of scientific institutions or research policies. Today we understand that the epistemological contribution of all these factors must be examined to fully understand the nature of contemporary and historical knowledge and its development. In both the traditional philosophy and history of science their role was severely underestimated.

The second aphorism of Bacon's *Novum Organum* states clearly what role instruments should play in the instauration of science:

> Neither the naked hand nor the understanding left to itself can effect much. It is by instruments and helps that the work is done, which are as much wanted for the understanding as for the hand. And as the instruments of the hand either give motion or guide it, so the instruments of the mind supply either suggestions for the understanding or cautions.[2]

It is significant that within the philosophy and history of science it was mainly the figurative meaning of this message that was celebrated: the scientific method of induction is understood metaphorically as a material instrument and therefore our attention is drawn primarily to the new method of investigating nature (instruments of understanding) rather than to the instruments for carrying out that investigation (instruments of the hand) it is compared with. A typical function of a metaphor is to elucidate some novel or uncertain aspect of a thing by comparing it to something familiar and known that remains further unquestioned – with the transfer of meaning our attention also shifts to the newly designated reality. Another factor contributing to the neglect of scientific instruments was the tradition of assigning mental and manual labour to two essentially different categories, at least since Aristotle's distinction between *epistémé* and *techné*, together with the differing social status of their representatives. True knowledge is an affair of the head, not the hand.

[2] Sidney WARHAFT, *Francis Bacon. A Selection of His Works.* Toronto: Macmillan 1965, p. 331.

We can find a lucid illustration of this tendency in Alexandre Koyré's assessment of Galileo's experiments. His contention is that Galileo never really went through with his experiments, they were simply illustrations of conclusions that he reached by logical reasoning:

> Good physics is made *a priori*. Theory precedes fact. Experience is useless because before any experience we are already in possession of the knowledge we are seeking for. Fundamental laws of motion (and of rest), laws that determine the spatio-temporal behaviour of material bodies, are laws of a mathematical nature. Of the same nature as those which govern relations and laws of figures and numbers. We find and discover them not in Nature, but in ourselves, in our mind, in our memory, as Plato long ago has taught us.[3]

Such idealist epistemology takes experiments only as rhetorical devices or at best as thought experiments. It is important to note, however, that here Koyré addresses Galileo's work with inclined planes, but elsewhere names the telescope "the first scientific instrument", and his general verdict – "One could even say that not only astronomy, but science as such, began, with Galileo's invention, a new phase of its development, the phase that we might call the instrumental one."[4] – is more cautious, although it has no serious influence on his history of science, which remains a history of ideas.

It is naturally important to differentiate between various kinds of instruments, apparatus and materials – a ball on an inclined plane will have different epistemological consequences than a telescope or an air-pump. Most of the pioneering works on experimentation and instruments dealt with seventeenth-century material because that was a time when, next to traditional measurement instruments, familiar since antiquity, a new kind of scientific equipment appeared. This equipment not only measured length, weight or time, it also disturbed and distorted nature and produced unnatural and extreme conditions through which to discover nature's secret truths. Their prime motivation was the search for truth rather than practical necessity, and they were most often used by scientists with more intellectual than practical interests. A distinction between "mathematical" (measurement) and "philosophical" (experimental) instruments gradually developed. This categorisation carries in itself the distinction between head and hand and

[3] Alexandre KOYRÉ, "Galileo and the Scientific Revolution of the Seventeenth Century." *The Philosophical Review*, vol. 52, 1943, no. 4, p. 347 (333–348).
[4] Alexandre KOYRÉ, *From the Closed World to the Infinite Universe*. Baltimore: The Johns Hopkins Press 1957, p. 90.

was motivated in part by the struggles for social recognition. However, it also opens up new aspects of technology. Philosophical instruments served the purposes of scientific investigation, but most of them were used for pedagogical purposes and public demonstration. They were the emblems of the work of natural philosophers, objects not only detecting but disclosing the workings of nature in performative and often spectacular ways. By forcing nature to reveal its mechanisms they also served the new breed of scientists as tools with which to demonstrate their powers of domination.

In the traditional philosophy of science, instruments were again only tangential. The most significant exception was the problem of the theory-ladenness of observation prominent in the post-positivist philosophy of science since the late 1950s. Simply put, it claimed that our experience is always conditioned by some prior understanding and our perceptions are guided by prior beliefs and expectations. Since scientific experiments involve observation, their meaning is possible only in relation to some prior theoretical background. Instruments don't simply read data from nature since they were designed to answer the particular questions posed by a given theoretical context. If we look closely at the writings of the originators of the idea, we discover that there are significant differences in what they understand by the term and also that there are certain limits to the ladenness of experimental data. For Norwood Russell Hanson, theory-ladenness is, first of all, causality-ladenness: there is a sense-datum language that describes effects, events and experiences and there is an explanation that finds causal links between them:

> Causal connexions are expressible only in languages that are many-levelled in explanatory power. This is why causal language is diagnostic and prognostic [...]. This is why within a context the cause-words are not "parallel" to the effect-words, and why causes explain effects but not vice versa. For "cause"-words are charged: they carry a conceptual pattern with them. But "effect"-words, being, as it were, part of the charge, are less rich in theory and hence less able to serve in explanation of causes.[5]

The main goal of science is explanation – diagnosis and prognosis – but Hanson's view makes possible theory-free perceptual accounts, their status

[5] Norwood R. HANSON, *Patterns of Discovery. An Inquiry Into the Conceptual Foundations of Science.* Cambridge: Cambridge University Press 1958, p. 60.

notwithstanding. Similarly, Pierre Duhem differentiates between a "concrete fact" and a "theoretical fact", between a fact and its theoretical interpretation:

> The result of the operations in which an experimental physicist is engaged is by no means the perception of a group of concrete facts; it is the formulation of a judgment interrelating certain abstract and symbolic ideas which theories alone correlate with the facts really observed.[6]

Again, we are here faced with a two-level model of scientific experiment, which consists of the observation of phenomena and their theoretical interpretation. The interpretation is not merely a statement of causal relationships, as it was for Hanson, but has also to inscribe phenomena into an abstract and symbolic structure. These phenomena, however, can be observed independently of theory, although their mere observation constitutes a preliminary, less advanced level of science. They have no meaning in themselves, they start making sense only after being incorporated into some theoretical framework. Popper sums up the theory-ladenness approach to experimentation in the following words: "Theory dominates the experimental work from its initial planning up to the finishing touches in the laboratory."[7] Scientific instruments are here intended to test theoretical hypotheses, they have no autonomous epistemological effect. The history of science is the history of scientific theories.

It was by turning to actual scientific practice that both philosophers and historians of science started to question the theory-ladenness view of experimentation. Ian Hacking's *Representing and Intervening* from 1983 sets out to do just that: show that the relationship between theory and experiment is far more complex than the hypothesis-testing theory suggests. While the first section of the book on "representing" surveys contemporary discussions of the realism of physical theories, the second one on "intervening" offers a novel treatment of experimental practice and scientific instruments.

> History of the natural sciences is now almost always written as a history of theory. Philosophy of science has so much become philosophy of theory that the very existence of pre-theoretical observations or experiments has been denied. I hope the following chapters might initiate a Back-to-Bacon movement, in

[6] Pierre M. M. DUHEM, *The Aim and Structure of Physical Theory*. Princeton: Princeton University Press 1991, p. 147.
[7] Karl R. POPPER, *The Logic of Scientific Discovery*. London: Routledge 2002, p. 90.

which we attend more seriously to experimental science. Experimentation has a life of its own.[8]

The Baconian impulse resides in turning away from theory and representation and towards interventions into the natural world, towards manipulations that produce new phenomena with which we can do something. Hacking presents a rich taxonomy of experiment-theory relationships that makes any effort to subsume them under some schematic model ultimately impossible. Although he has successfully challenged the traditional problem of theory confirmation, he has not disposed of it. The next logical step was to turn from experiments to instruments, to the actual material culture of scientific research.

Here another conceptual transfer was needed and this time the inspiration came from object-oriented anthropological, sociological and ethnological methodologies. These approaches to material culture and its history tend to stress the uses, circulations and transactions through which objects acquire meaning and value. The identity of an object is not given by the purpose it was produced for but can develop and transform through its social life.

> Even if our own approach to things is conditioned necessarily by the view that things have no meanings apart from those that human transactions, attributions, and motivations endow them with, the anthropological problem is that this formal truth does not illuminate the concrete, historical circulation of things. For that we have to follow the things themselves, for their meanings are inscribed in their forms, their uses, their trajectories. It is only through the analysis of these trajectories that we can interpret the human transactions and calculations that enliven things. Thus, even though from a *theoretical* point of view human actors encode things with significance, from a *methodological* point of view it is the things-in-motion that illuminate their human and social context.[9]

This "methodological fetishism" found its echo in the philosophy and historiography of science of the late 1990s, where the primary focus was directed at the epistemological effects of scientific things – instruments and materials.

[8] Ian HACKING, *Representing and Intervening. Introductory Topics in the Philosophy of Natural Science.* Cambridge: Cambridge University Press 1983, p. 149–150.
[9] Arjun APPADURAI, "Introduction: Commodities and the Politics of Value." In: Arjun APPADURAI (ed.), *The Social Life of Things: Commodities in Cultural Perspective*. Cambridge: Cambridge University Press 1986, p. 5 (3–63).

Let's give an example of this shift of emphasis with another traditional problem, that of tacit knowledge. In *Personal Knowledge* and *The Tacit Dimension*, Michael Polanyi criticised the idea that knowledge has to be expressed in language. All knowledge, that is: apart from verbally communicated knowledge there are other kinds of knowledge that take on different forms. "I shall reconsider human knowledge by starting from the fact that *we can know more than we can tell*."[10] Tacit knowledge is our implicit routines and skills, our beliefs, ideals and mental models, which are difficult if not impossible to communicate. A classic example of such know-how is riding a bicycle: there is no known principle by which a cyclist keeps his balance, there are no formal rules that guide such practice and by which one would learn to ride a bicycle. It is a kind of practical knowledge that resides solely in a type of skilful performance.[11] Whose knowledge is it exactly, where can we locate it? Whereas for Polanyi and from the theoretical point of view it is a kind of "human" knowledge, add some methodological fetishism and the perspective turns around:

> We say someone knows how to ride a bicycle when he or she can consistently and successfully accomplish the task. A phenomenon such as that exhibited by Faraday's motor shares these features of consistency and success with what usually is called know-how or skill knowledge. One might say that Faraday's motor "knows how to make rotations," but that overanthropomorphizes the motor. I prefer to say that the motor bears knowledge of a kind of material agency.[12]

Baird's *Thing Knowledge* is so far the most systematic account of a materialist epistemology of scientific instrumentation. It claims that not only theory but instruments as well convey knowledge and that this knowledge has to be understood as equal yet distinct and autonomous – only then we will be able to have a full account of science. Knowledge resides not only in minds but also in things. Things have epistemic significance independently of that expressed by theories; their epistemology must go beyond the traditional propositional and mentalist epistemologies. Furthermore, there cannot be a single, universal material epistemology because there are essentially different kinds of instruments (Baird distinguishes models that represent

[10] Michael POLANYI, *The Tacit Dimension*. Gloucester: Peter Smith 1983, p. 4.
[11] Michael POLANYI, *Personal Knowledge. Towards a Post-Critical Philosophy*. London: Routledge 1958, pp. 51–52.
[12] Davis BAIRD, *Thing Knowledge. A Philosophy of Scientific Instruments*. Berkeley: University of California Press 2004, p. 15.

phenomena, measuring instruments, and performative instruments that create phenomena). Instruments have what he calls cognitive autonomy – the development of instrumentation can proceed in partial and sometimes nearly complete independence of theory.

Epistemology engines

I have sketched an outline of the gradually changing attitude towards instruments and materials in the philosophy and history of science – it proceeds from ignorance, neglect, marginalisation and the degradation of the roles and functions of instruments in scientific research to their revaluation, appreciation, and even "fetishistic" celebration. No doubt this tendency has significantly contributed to a better understanding of what science was and is and how it worked and works. However, there is one crucial aspect that is often missing from these accounts, since the problems of materiality are treated only in terms of the development of theoretical or historiographical discourse. We should also acknowledge that in between the material level of scientific research and its theoretical reflection there are various strata of mixed nature that mediate between these two ideal types.

Although there are quite a few different approaches that can address this gap and help to overcome it, I will highlight two that I find most stimulating: one from a historian and one from a philosopher of science and technology.

The first approach, here exemplified by Hans-Jörg Rheinberger, proceeds via criticism of the traditional model of scientific experiment. Recall Popper's formulation, in which the development of knowledge is driven by theoretical hypotheses that are being tested by the experimental and instrumental side of research. The first objection to this model states that there is never any singular, isolated experiment that the scientist designs in response to a theoretical question, but that one deals rather with a complex experimental arrangement that creates knowledge that one does not yet possess. We should therefore rather speak about experimental systems that are not rigorously defined and offer no clearly formulated questions. They are not tools for generating answers but rather materialise questions and generate material entities along with concepts and theories.

In such an experimental system we can discern two distinct yet inseparable elements. The first one is the research object – a material entity or a process, such as a physical structure, a chemical reaction or a biological function that constitutes the object of inquiry –, which Rheinberger calls an "epistemic thing". The second one is the "technical object", the experimental conditions of research.

> It is through them that the objects of investigation become entrenched and articulate themselves in a wider field of epistemic practices and material cultures, including instruments, inscription devices, model organisms, and the floating theorems or boundary concepts attached to them. It is through these technical conditions that the institutional context passes down to the bench work in terms of local measuring facilities, supply of materials, laboratory animals, research traditions, and accumulated skills carried on by long-term technical personnel.[13]

Experimental conditions contain the epistemic thing – they embed it, allow it to manifest itself, yet at the same time constrain and restrict it. If the scientific object becomes stable enough, it can turn into the technical repertoire of the experimental arrangement. Therefore, the difference between experimental conditions and epistemic things is merely functional; we cannot draw any definite or substantial divisions between these elements of the system. And it is precisely thanks to these shifts, reconstructions, mutual exchanges and transformations that the experimental system can constantly innovate itself and generate new knowledge. Although the role of a certain entity depends on the place it occupies in an experimental context, although the roles can and do change and we can even find hybrids that would be difficult to situate on either side, the distinction is maintained in scientific practice and, according to Rheinberger, "it helps to assess the game of innovation, to understand the occurrence of unprecedented events and with that, the essence of research."[14]

The second approach proceeds not through a minute analysis of the research process but rather through situating the production of knowledge within the practices and attitudes of the lifeworld. Here, the intellectualist history of science is modified by the phenomenological insight that practical coping precedes theoretical reflection: theoretical thought should be placed on a continuum with the practical lifeworld activity that exerts a strong metaphorical influence over how things – including matters of epistemology – are conceived and interpreted. To assess the epistemological value of materiality, Don Ihde coins the term of an "epistemology engine":

[13] Hans-Jörg RHEINBERGER, *Toward a History of Epistemic Things. Synthesizing Proteins in the Test Tube*. Stanford: Stanford University Press 1997, p. 29.
[14] *Ibid*., p. 31.

> An "epistemology engine" is a technology or a set of technologies that through use frequently become explicit models for describing how knowledge is produced. The most dramatic examples of "epistemology engines" influence our notions of subjectivity, directly affecting how we understand what it means to be human and to perceive things from a human perspective. They enable us to draw connections between the knowledge producing capacity of the human mind and technologies that putatively function according to similar mechanical processes. The philosophy of mind is replete with theorists modeling the brain, which even today is poorly understood, on technologies whose design is better understood. An epistemology engine is thus a special case of a more general phenomenological notion that entails the ways in which lifeworld practices form the basis for what often become scientific theories.[15]

Some instruments suggest or inspire our knowledge – such as the notorious example of the steam engine that motivated ideas of entropy and the second law of thermodynamics, although it developed without any systematic and explicit scientific theory. Some instruments do more than just suggest new phenomena and their conceptual understanding; they can serve as true models of how people perceive, think, acquire and generate knowledge. Camera obscura is the classic example of such an epistemology engine, since next to its practical uses it also functioned as an epistemological figure, as a metaphor of the eye and the mind.

A few years before Ihde introduced his concept of the epistemology engine, a similar emphasis on the epistemological gain of camera obscura appeared in Jonathan Crary's rereading of modern visual culture.[16] In a Foucauldian manner, Crary questions traditional accounts that assume a more or less linear development of visual technologies – the progress towards more complex and sophisticated means of achieving pictorial verisimilitude that starts with renaissance inventions of linear perspective and camera obscura and continues through nineteenth-century photography, twentieth-century film and television to contemporary technologies of virtual reality. What makes this generally accepted view of visual history problematic is

[15] Don IHDE – Evan SELINGER, "Merleau-Ponty and Epistemology Engines." *Human Studies*, vol. 27, 2004, no. 4, p. 362 (361–376). The concept was introduced in Don IHDE, "Epistemology Engines." *Nature*, vol. 406, 2000, no. 6791, p. 21.

[16] See especially Jonathan CRARY, "Modernizing Vision." In: Hal FOSTER (ed.), *Vision and Visuality*. Seattle: Bay Press 1988, pp. 29–44; Jonathan CRARY, "Techniques of the Observer." *October*, vol. 45, 1988, pp. 3–35, and Jonathan CRARY, *Techniques of the Observer. On Vision and Modernity in the Nineteenth Century*. Cambridge: The MIT Press 1990.

that it builds exclusively on privileged forms of images (art history) and that it presupposes an unchanging "natural" attitude of observers to them. By discussing the ways visual forms and technologies are embedded within the larger cultural contexts and forces that make up the field in which perception occurs, Crary distinguishes between different scopic regimes. During the seventeenth and eighteenth centuries the camera obscura was "the most widely used model for explaining human vision, and for representing the relation of a perceiver and the position of a knowing subject to an external world."[17]

This model was built on two interrelated assumptions. First, the inside is differentiated form the outside, a barrier separates the dark space of the human mind from the lucid surrounding world, which enters through the peephole and draws its image in the interior space. The second fundamental assumption is one of correspondence between inside and outside images; the model and its copy are in an accordance that is guaranteed by the mechanism of the camera obscura built on scientific principles. The camera obscura is thus

> a figure for the observer who is nominally a free sovereign individual but who is also a privatized isolated subject enclosed in a quasi-domestic space separated from a public exterior world. [...] The visual world could be appropriated by an autonomous subject but only as a private unitary consciousness detached from any active relation with an exterior. The monadic viewpoint of the individual is legitimized by the camera obscura, but his or her sensory experience is subordinated to an external and pre-given world of objective truth.[18]

In the seventeenth and eighteenth centuries, the camera was the dominant model for both rationalists and empiricists of how observation leads to truthful inferences about the world. According to Crary, this model collapses in the early nineteenth century thanks to new experimental research in physiology, which tends to understand vision in more material, corporeal, and temporal terms. Within our understanding of the production of (scientific) knowledge, however, the model still retains some currency and should be replaced by different engines that, first of all, are not based on the concealment of their own materiality.

[17] CRARY, *Techniques of the Observer*, p. 27.
[18] CRARY, "Modernizing Vision.", p. 33.