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The media perspective in the study of scientific abstraction

What I have chosen to refer to as the "media perspective" is a way of looking at science, its history and its philosophy which has been successfully employed in a number of recent studies. In these works, the term "medium" rarely occurs, but I believe that the experiences of media studies can be very helpful for historians and philosophers of science in looking at things from this perspective. This approach deserves to be explicitly put into focus, and I will try to do so with a number of examples.

Scientific knowing between production and communication

Scientific knowing is a process resulting both in new concepts and in new forms capable of expressing them, two aspects which can be distinguished only in a first approximation.

This remark may seem quite trivial, as it applies not only to science, but to a much broader range of human activities. However, in science the dynamics of form and content has a unique character because of the great variety of elements which can take part in it: material objects, symbolic and linguistic codes - each with its own rules - codified descriptions, pictorial and non-pictorial images, numbers, moving displays, tables, standardized procedures - and more. In fact, any a priori limitation of this list would be regarded by many as non-scientific.

If knowledge is never independent from its modes and contexts of production and communication, the above list corresponds to an equally unlimited variety of knowing enterprises. At the same time, scientific knowing seems to be characterized by a drive never to rest in one medium, be it word, experimental set-up, number or operational definition. The result is a constant tension between theory and practice, an entanglement of materiality and abstraction whose richness grows with technical possibilities.

Looking at the above list of elements participating in the scientific enterprise, one might be tempted to distinguish between tools to produce knowledge, on the one side, and symbolic forms to communicate it, on the other. In fact, though, a number of recent studies have shown how each of the elements listed above can play the role both of a symbol and of a tool, often at the same time.[1] The "abstract concept" dissolves between production and communication, and it is therefore very important to pay attention to the all elements taking part in both processes, and also to shifts and mixtures between one element and the other.

For example, one has to be aware of the shift between the codified description of a standard procedure and its actual performance, or between a mathematical formula, its verbal interpretation and its computational implementation to obtain numerical results. Such differences can be obscured when speaking of "temperature measurement" or of "the law of universal gravitation".

In this paper, I would like to discuss two fields in which I believe looking at things from this perspective can be a particularly fruitful complement to other approaches in science studies. The first field relates to the construction and use of instruments and, more in general, of material set-ups, the second one to quantification and mathematisation of science and in science.

Construction as reflection

Instruments do not only contribute as tools to the production of new scientific ideas: they can also come to be regarded as an embodiment of pre-existing concepts - "pre-existing", though, in another form.

For example, late medieval mechanical clocks were seen as embodying the idea of "temperance", i.e. of self-regulation: of a stable middle state between two extremes, a state to which a system is drawn back when straying from it.[2] This was a central concept in medieval Aristotelian philosophy, and the earliest images of mechanical clocks show us that medieval people were just as interest in the self-regulating inner mechanisms of the clocks as in their outer displays.

The same could happen also with other kinds of material set-ups, as for example chemical experiments. In medieval and early modern times, the process of distillation of alcohol was seen as representing the idea that there is no clear-cut opposition between body and soul. Instead, a "spiritual" component could be extracted from matter step by step, by a process of refinement which was not a

[1] To quote only a few: P. Galison, *Image and logic. A material culture of microphysics* (Chicago: University of Chicago Press, 1997); H.-J. Rheinberger, Instrumente und Objekte im experimentellen Kontext der Wissenschaften vom Leben, in: H. Schramm, L. Schwarte and J. Lazardzig (eds.), *Instrumente in Kunst und Wissenschaft* (Berlin: de Gruyter, 2006) pp. 1-20; L. Roberts, S. Schaffer and P. Dear (eds.), *The mindful hand. Inquiry and invention from the late Renaissance to early industrialisation* (Amsterdam: Koninklijke Nederlandse Akademie van Wetenschappen, 2007).

[2] L. White jr., The iconography of 'Temperantia' and the virtuousness of technology, in: L. White, jr., *Medieval religion and technology. Collected essays* (Berkeley: University of California Press, 1978) pp. 181-204.

mechanical separation, but rather resembled the distillation of spirits from wine or from other substances.[3]

Once a material set-up comes to be regarded by some as representing specific conceptual structures, the act of experimenting in its construction and use can acquire a significance going well beyond the immediate results of the experiment. The whole process can be an (abstract) reflection in a form more material than that of a few symbols written on paper.

Looking at things from this perspective has helped better understand early modern instruments and experiments: astronomical clocks, mechanical and pneumatic devices, alchemical practice.[4] For the most part, these products were neither useful tools, nor crucial experiments, nor toys for adults: they might be regarded as reflections guided by the initiative of human actors, the broader social and cultural context and the premises and constraints of the material set-ups. Different material set-ups could be linked to different world-views: mechanical philosophy to mechanical automata, chemical philosophy to (al)chemical experiences, libertarian philosophies to self-regulating, feed-back devices.[5]

Moreover, reflections made in different material forms could be coupled with diverging conceptions of "true knowledge". For mechanical philosophers, the paradigm of knowledge were often the disembodied geometrical structures necessary for constructing clockworks. For craftsmen and alchemists of the Renaissance, instead, knowledge was something that had to be reached by bodily activity, and that implied some material effect.[6]

Entanglement between the material and the abstract

Conceptual structures developed as material set-ups are often transposed into another form - for example a text or a formula, although early modern alchemists were much more creative. In the process of transposition, instruments and procedures can be translated into a verbal, graphical or symbolic form, to become themselves a theory. This was the case of the (impossible) 'perpetuum mobile' and

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[3] F. S. Taylor, The idea of the quintessence, in: E. A. Underwood (ed.), *Science, medicine and history. Essays in the evolution of scientific thought and practice written in honour of C. Singer*, vol. 1 (London: Oxford University Press, 1953) pp. 247-265.

[4] D. Bertoloni Meli, *Thinking with objects. The transformation of mechanics in the seventeenth century* (Baltimore: The John Hopkins University Press, 2006); A. G. Debus, The Paracelsian aerial niter, *Isis* 55 (1964): 43–61.

[5] A. Borrelli, Pneumatics and the Alchemy of Weather: What Is Wind and Why Does It Blow?, in: S. Zielinski and E. Fürlus (eds.), *Variantology 3. On deep time relations of arts, sciences and technologies* (Cologne: Verlag Walther König, 2007) (forthcoming); O. Mayr, *Authority, liberty, and automatic machinery in early modern Europe* (Baltimore: The John Hopkins University Press, 1986); D. J. de Solla Price, Automata and the origins of mechanism and mechanistic philosophy, *Technology and Culture* 5 (1964): 9–23.

[6] P. H. Smith, *The body of the artisan. Art and experience in the scientific revolution* (Chicago: University of Chicago Press, 2004).

of steam-engines, whose behaviour was schematised in 'Carnot's engine', a concept central to thermodynamics.

Sometimes, this kind of translations are regarded by historians or philosophers as metaphors, as for example the clockwork-universe metaphor of late medieval and early modern times. Although the meaning of the term "metaphor" is itself open to much discussion, it is important to note how these metaphors were often more than superficial analogies, and that, in studying them, one has to keep in mind their material origin: clockwork-metaphors from the years 1400, 1600 and 1800 can be as different as the clocks of those ages.

In modern science, the complex relationship between abstract and material devices is particularly fascinating, for example in "operational definitions", when temperature is defined as that which is measured by a thermometer, or electrical charge is defined as that which can be detected by following certain procedures. More often than not, operational definitions involve the description of measurement units defining a physical quantity.

Operational definitions are so important to the conceptual architecture of modern science, that it has been (unsuccessfully) attempted to reduce all scientific concepts to operationally defined ones.[7] Operational definitions are verbal descriptions coupled with very precise, codified graphical, symbolical and numerical statements. They are not "thought experiments", on the contrary: they are specifically formulated (1) to imply that all information they contain comes from experiences actually performed, (2) to allow the exact reproduction of those experiences, and (3) to serve as reference point for future, as-yet-untried experiments. Still, an operational definition is usually not the immediate description of an actually performed procedure, and standard instruments are not real, individual instruments.

For example: the unit of temperature (Kelvin), is defined in terms of (at least) four completely different standardized measuring systems ("thermometers"), each working in a different temperature range, with overlapping edges.[8] These technical aspects of the definition are then connected with the formal - though not fully mathematical - apparatus of thermodynamics, to finally define the Kelvin.

This process might at first look like an "upward" shift from the material-experimental level to the theoretical-symbolic one, but it is no such thing. In most cases, when experimentally studying the behaviour of one part of a material system, one makes assumptions in symbolic-theoretical form on the properties of another part of the same system - e.g. when observing the expansion of mercury in a thermometer, one has to make assumptions on the expansion rate of the glass casing of that same thermometer. Those assumptions are of course derived from experience, but they are mediated in verbal, numerical or graphical form. In the end, standardized instruments and procedures are made out of an entanglement of material, symbolic, verbal and graphical elements. I say "entanglement", because

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[7] G. Schlesinger, Operationalism, *Encyclopedia of Philosophy. Second Edition* 7 (2006) pp. 29-33.

[8] A detailed discussion of the definition of the Kelvin scale can be found for example in: J. Fischer and B. Fellmuth, Temperature metrology, *Rep. Prog. Phys.* 68 (2005): 1043-1094.

these devices cannot be regarded as material or abstract "in degrees", as though the shift from materiality to abstraction, from body to mind, were something linear. In fact, each material-experimental step in one directions can bring with it an abstract-theoretical step in another one, and different devices move in completely different directions.

To appreciate the composite nature of such a construct one has to look into the details of each instance, trying to reconstruct how a quantity comes to be and goes on living as both *a* quantity and *that specific* quantity resulting from *that specific* process.

In other words, quantities are abstract constructs, but it still does make a difference whether a quantity is measured with an instrument, counted on the fingers or given as output by a formula or a computer simulation.

Mathematics, the senses and mathematical apparatuses

Not only quantities, but in general mathematical objects are not usually considered as something which can be bodily experienced - and experienced in a number of different ways. However, mathematical statements have to be learned, communicated and employed through sensory and bodily experience, and these bodily aspects of mathematics can make a great difference as to how mathematical statements and their implications are conceived.[9]

Taking this fact into account is very important when studying pre-modern epochs, where mathematical statements could be expressed in logically ordered verbal statement, which one went through as steps on a ladder, or in the form of geometric constructions performed with ruler and compasses. [10] In the latter case, a clear-cut distinction between theory and practice was hardly possible.

Perhaps the best known example of this dynamics is the history of Newton's laws of motion, from their formulation by Newton as verbal, Latin statements to the form Euler put them in, which looks almost exactly like the one in today's textbooks. Newton's laws were not -could not be - the same as Euler's.[11]

In modern times, the complexity both of written notations and of computational systems has grown enormously. I believe it would be of the greatest interest to study under this perspective at least one single instance of the

[9] On this subject, see for example: M. Ascher, *Ethnomathematics. A multicultural view of mathematical ideas* (New York: Chapman & Hall, 1994); B. Rotman, *Mathematics as sign. Writing, imagining, counting* (Stanford: Standofrd University Press, 2000).

[10] W. Lefevre (ed.), *Picturing machines: 1400-1700* (Cambridge MA: MIT Press, 2004); A. Borrelli, The flat sphere, in: S. Zielinsky and D. Link (eds.), *Variantology 2. On Deep Time Relations of Arts, Sciences and Technologies* (Köln: Verlag Walther König, 2006) pp. 145-166; A. Borrelli, *Aspects of the astrolabe: 'architectonica ratio' in tenth- and eleventh-century Europe* (Stuttgart: Steiner, forthcoming).

[11] G. Maltese, The ancient's Inferno: the slow and tortuous development of 'Newtonian' principles of motion in the eighteenth century, in: A. Becchi et al., *Essays in the history of mechanics. In memory of Clifford Ambrose Truesdell and Edoardo Benvenuto* (Basel: Birkhäuser Verlag, 2003) pp. 199-221.

employment of computers in scientific computations, simulations and data-analysis. Here I mean investigating not just algorithms, inputs and outputs, but all levels of software and hardware, as well as their interaction with humans. Very often, these aspects are discussed by substituting them with schematic representations, mathematical formulas and logic diagrams - again, a shift.

Even when only written symbolic formalism is involved, not all mathematical formulas and mathematical methods are equivalent: specific formalisms and methods can suggest specific ways in which the objects presented can be manipulated in a sort of virtual kinaesthetic experiences. Such a case has been analysed by Ursula Klein in nineteenth-century chemical notation.[12] To describe the function of the changing symbolism, she has introduced the term "paper tool".

In modern physics, the situation is often more complex than in chemistry. Even within the same notation and the same physical-mathematical theories (e.g. classical or quantum mechanics), scientists can choose from a great variety of models and methods to frame and solve problems. Each method has its own premises and inner rules, and it is not unusual for different methods to be not fully compatible with each other. These complexes are more like gigantic "paper apparatuses" than like "paper tools", and theoretical scientists can often choose, combine and modify them in very creative ways, trying to connect them with the one or the other experimental input.

In conclusion, the practice of mathematical theory is not just an interplay between mathematical forms and physical concepts taking place in the mind of a scientist, but rather the conflict and conflation between different mathematical-physical-digital (and sometimes also verbal and philosophical) apparatuses being used and transformed by a collective of human agents. It can be very interesting to look at mathematics, too, from a media perspective.

[12] U. Klein, *Experiments, models, paper tools. Cultures of organic chemistry in the nineteenth century* (Stanford: Stanford University Press, 2003).