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Reviewed work(s):
Source: *Transactions of the Charles S. Peirce Society*, Vol. 24, No. 2 (Spring, 1988), pp. 161-178
Published by: Indiana University Press
Stable URL: http://www.jstor.org/stable/40320207
Accessed: 25/02/2013 15:47

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I. The Matter of Models

For at least a century now a significant number of working scientists have been prepared to speak of their efforts to theorize about natural phenomena as "attempts to model" or "to build models" of the aspects of nature which they were investigating. The status of this activity, *modeling*, and of its products, *models*, has from time to time been a topic of debate among those who take a philosophic interest in science. Modeling does not fit comfortably into some accounts of what theoretical activity is supposed to be, and those attracted to such accounts have tended to argue that the activity is peripheral to science proper. Models, they allege, are mere instruments which aid in the generation of scientific theories, rather than vital organs, which constitute a scientific theory. Others have insisted that models and modeling are essential parts of scientific theorizing and any account which relegates them to the status of mere "stimulants to thought" or "psychological crutches" has misapprehended the nature of scientific thought.

We have here what can be described in Aristotelian terms as a dispute about the material causes (*aitiai*) of scientific theorizing, a dispute extending over two inextricably linked categories. For the question is both whether modeling is a proper constituent of theorizing (activity/process) and whether models are proper constituents of scientific theories (vehicles/products). Thus Rom Harré is commendably cautious about the dangers of giving "quasi-substantial status" to propositions, pictures and models.[1] But bearing in mind how such "vehicles of thought" are ontologically dependent on the activities of thinking, Harré goes on to identify as one of the "myths of deductivism" the belief that language is "*the* [only] vehicle for thought" (p. 8). This is not to say that 'icons' are *the* (only) vehicles for thought, but rather that the typical vehicle, especially of scientific thought is a "statement-picture complex," an icon depicting a structure together with a "statement of how the structure depicted will react to appropriate stimuli." (p. 12).

What Harré labels a "myth of deductivism" is indeed a clearly identifiable tendency in a widely dominant tradition in the philosophy of science going back to Pierre Duhem at the beginning of this century. But naturally deductivists will allege that the shoe of "myth" should be worn on the other foot. The picture, model or diagram is not, they would claim, a constituent of the edifice of a scientific theory; it is at best "scaffolding intended to be removed."[2] The fabric of the theoretical edifice is a logically articulated structure of propositions; images which may have informed the minds of its architects are not more a part of the structure than are specifications and blueprints parts of the fabric of a cathedral or skyscraper.

If one looks closely at Harré's definition of 'an *iconic* model' (p. 33,36), the deductivist will point out, one will see that it is defined in terms of a 'sentential model'. A domain, M, iconically models a domain, N, if each sentence, q, about the objects of N can be matched to a sentence, p, about the objects of M in such a way that q is acceptable (unacceptable) if and only if p is true (false). Does this definition not show that what a picture model or diagram conveys is ultimately to be expressed in sentences (propositions)?

Harré would probably reply that there may well be more sentences true about M (thereby determining what should be said about N) than can be deduced from any finite set of axioms about M. The model may well be an inexhaustible source of new theoretical pronouncements.[3] Thus to advance a "statement-picture complex" is to do more than can be done by advancing a logically articulated structure of propositions. But the deductivist will treat each new theoretical pronouncement not deducible from the existing theory as a new hypothetical axiom and the statement-picture complex as representing at best a series of separate theories, successively more elaborate. Psychologically the picture (or whatever it is most appropriate to call the icon) may have been the source of the successful elaboration, but a source of inspiration is not the same thing as a part of the theory.

One might expect that a dispute about whether some means is appropriate for constituting an artifact (in this case a scientific theory) is the result of different conceptions of the use to which the artifact is to be put. Aristotle's conclusion that one cannot make a saw out of wood (*e.g. Physics* II.9) is sound only under the assumption that the purpose of (what we call) a saw is to cut wood. And indeed Harré links the issue of the vehicles of thought with that of whether the aim of scientific theory is to represent the causal mechanisms, the structure underlying and explaining natural phenomena. He argues, "characteristically structure is presented diagrammatically (by pictures and models). . ." (p. 13).

However, not all deductivists repudiate the representation of non-apparent (underlying and explanatory) structure as a legitimate goal for scientific theory. And even where this goal is repudiated (e.g. by Duhem, A 7), the connection between this issue and that of the place of iconic vehicles is very tenuous. Harré contends that the exclusive concentration on statements as vehicles gives rise to "the idea that event-series are the only true objects of knowledge" because, "Characteristically . . . the possibilites of change [are presented] sententially as conditional statements" (*ibid.*). It is not difficult, however, to think of conventions whereby icons could effectively represent the possibilities of change in that which they represented. Moreover, on the other hand, axiomatic systems are precise and powerful vehicles for presenting abstract, relatively permanent (even eternal) structure.

Harré does not explain very clearly what it is we stand to lose by foreswearing the use of iconic vehicles in the expression of (what we hope is) our scientific understanding, but it is equally not clear what it is we risk if we regard theories as constituted in part by such vehicles. Of course a model, even one which has for some time yielded fruitful hypotheses may prove to have limited value as it starts to yield unacceptable hypotheses. But in same way a deductively articulated set of hypotheses and their consequences may, as it is developed, cease to have only consequences which are born out experimentally. In the latter case we look for a better set of hypotheses; in the former we are free to look for a better model. Why then treat the model as an inessential element in the activity of theorizing, but treat sententially expressed hypotheses as constituting the pulsating heart of a theory?

It is difficult not only to see what is at issue between the strict deductivist and the advocate of iconic vehicles, but also where the burden of proof should lie. It is commonly assumed that the advocate of iconic vehicles needs to prove that we suffer some crippling loss by classifying such vehicles among the peripherals of theory; in the absence of such a proof icons are best regarded as externals. But is there any positive reason why we should (if we can) disregard icons as elements of a scientific theory? Aristotle's claim that one cannot make a saw out of wood rested not only on an assumption about what we want to do with a saw but also on the inability of wood as material to retain certain shapes under certain stresses. Are icons similarly unsuitable material for embodying and conveying scientific understanding?

The attack early in this century, which Pierre Duhem launched against the role of models in scientific theorizing, does include a strong indictment of iconic thought for its unsuitability to constitute any element of a scientific theory. The indictment, at least, is clear, even if its grounds are somewhat obscure. Duhem's argument rests on a sharp distinction between reason and imagination and a psychological typology which opposes the strong narrow (French and German) scientific mentality to the ample but weak (English) mentality. Men possessed of the latter follow the lead of Gassendi (an atypical ample-but-weak minded Frenchman) who insisted, "that the mind is not really distinguished from the imaginative faculty" (A 87). Duhem clearly shares Descartes' "haughty disdain [for] the imagination that is limited to concrete objects" (A 88). Abstract physical theory is the product of the strong, rigourously incisive activity of Pascal's "exact" (as opposed to "geometrical") mind (A 57, citing *Pensées,* Art VII.2).

Models, whether geometrical, algebraic or mechanical are unsuitable for physical theory because of their association with the despised imagination, "for skill in algebraic calculation is not a gift of reason but an ornament of the imaginative faculty" (A 76). A French or German physicist uses algebra for convenience, as a substitute for a series of syllogisms (A 79); he is "often disconcerted" (A 80) by the English practice of regarding the algebra "as playing the part of a *model*" (A 79). "He does not realize that all he has before him is a model mounted to satisfy his imagination rather than his reason" (A 80). "It cannot be doubted that reason requires us to prefer [Helmholtz's] theory but imagination prefers to play with the elegant algebraic model fashioned by Hertz . . . Heaviside and Cohn" (A 91).

But what is imagination that it is capable only of producing distracting playthings, that its "needs" cannot be satisfied at the same time as the "requirements of reason" (A 103)? Its objects are "those falling within the purview of the senses, they must be tangible or visible" (A 56). Ample but weak minds "have a wonderful aptitude for holding in their imaginations a complicated collection of disparate objects" (*ibid.*) but they are not driven to co-ordinate these diverse incoherent fragments into a single system. They do not further the goal to which "[e]very physicist naturally aspires . . . the unity of science" (A 103). This unity is to be achieved only through, "a system of mathematical propositons, deduced from a small number of principles, which aim to represent as simply, as completely and as exactly as possible a set of experimental laws" (A 19). That there is a role anywhere in this for imagination, that the imagination might be capable of functioning under the discipline of reason Duhem nowhere considers.

II. Imagination and the Discipline of Reason

It is this failure even to consider how imagination could work with reason that would have rendered Duhem's arguments worthless in the eyes of his older American contemporary Charles Sanders Peirce.[4] Peirce began philosophy as a committed Kantian and never abandoned the Kantian idea that an imaginative ability was necessary for the full use of judgement and reason and that imagination could function in a "pure" form under the discipline of reason. A comparison of Duhem with Peirce on this issue is attractive partly because of their similar professional backgrounds – both were scientists and students of the history of science – but largely because of the curious enantiomorphic relationship in which they stood to one another over the deductivist conception of science.

It is often thought that the twentieth century form of the deductivist conception of science is a product of advances in logic begun in the nineteenth century. A more comprehensive conception of deductive reasoning made it more plausible to think of the ideal scientific theory as consisting entirely of a structure of propositions deductively articulated. Duhem, as fervent and unequivocal a champion of this conception as one could hope to find, seems untouched by the advances in logic that were made in his lifetime. He commonly refers to deductions as syllogisms; he does not mention Boole, Schröder or Frege in *The Aim and Structure of Physical Theory.* He might well have taken as dim a view of the application of algebraic techniques to logic as he took of their application to physical theory. On the other hand, Peirce, who has a claim to be included with Boole, Schröder and Frege, as one of the founders of modern logic, regarded deduction as but one of three important forms of logical articulation in scientific thought. And far from regarding the use of iconic vehicles of thought as beneath the dignity of reason, Peirce saw 'diagrams' as legtiimate tools of scientific thought, as the very subject matter of mathematics and as a proper basis on which to develop a comprehensive logical theory.

Eight years before the publication of Duhem's *Aim and Structure of Physical Theory* Peirce published an article,[5] which opened with a warm defense of one form of iconic vehicle of thought, the 'diagram'. By 'diagram' Peirce meant something more general than 'geometric (or topological) schema,' for algebraic formulae also counted as diagrams. Although he does not use the word 'model,' and Duhem hardly uses the term 'diagram', it is clear that the two stand diametrically opposed on the same issue. Peirce began by introducing his reader to the project of setting out a "System of diagramatization by means of which any course of thought can be represented with exactitude" (4.530). "Why do that," he imagined his reader asking, "when the thought itself is present to us?" For the same reason, Peirce replied, that a general who has been familiar with the terrain of the battlefield since his youth will still use a map, viz. to experiment with the deployment of his own and his enemy's forces. One can make on a uniform diagram, exact experiments which lead to the discovery of unintended and unexpected changes in the significant relations represented on the diagram.

> Chemists have ere how, I need not say, described experimentation as the putting of questions to Nature. Just so, experiments upon diagrams are questions put to the Nature of the relations concerned. (*ibid.*)

But surely there is all the difference in the world between experimenting on the "Very Object under investigation" and experimenting on something which bears no physical connection with what it represents? Indeed there is, but it is far from clear that such a difference obtains here. The Very Object under the chemist's investigation is a certain Molecular Structure and he takes considerable pains to ensure that his samples are sufficiently pure, etc. so that his experiment will be on that Very Object. The object of his investigation is not the sample he operates upon; the question his experiment puts to Nature is about a Molecular Structure, "which in all his samples has as complete an identity as it is in the nature of Molecular Structure ever to possess" (*ibid.*). And in the case of someone experimenting on a diagram, the Very Object under investigation is the *form of a relation,* and that form is to be found obtaining between the parts of the diagram, just as the Molecular Structure is to be found in the sample.

Peirce does not mean to ignore the distinction between the two cases, for properly understood they display the different methods which for Peirce distinguish the mathematical from the natural sciences. When a mathematician is given a problem arising in the natural world, it is not his responsibility as a mathematician to verify the facts as they are presented to him. "He accepts them absolutely without question" (3.559, although Peirce probably should have added, 'apart from checking whether they appear to be consistently stated'). What the mathematician usually finds, however, is that the facts in their full complexity are too intricate for him to make any exact statement about their consequences. So his first, and often most difficult, task is "to frame another simpler but quite fictitious problem . . . which should be within his powers" (*ibid.*). The problem which he substitutes, in addition to simplifying the relevant relations he was given, omits all features which have no bearing on the problem, in effect stripping "the significant relations of all disguise" (*ibid.*).

Evidently there is scope for the simplified problem to over-simplify or omit something significant, but according to Peirce's account, the mathematician does not act *as* a mathematician when he considers whether this might be the case. It is the role of a natural scientist to do this. From this simplified problem the mathematician proceeds to draw necessary consequences and his procedure from this point is like that of the chemist.

> Thus, the necessary reasoning of mathematics is performed by means of observation and experiment, and its necessary character is due simply to the circumstance that the subject of this observation and experiment is a diagram of our own creation, the conditions of whose being we know all about. (3.560)[6]

For Duhem, for whom mathematical methods begin and end with axiomatics (A 73), this account would be nothing short of a travesty. Of course some mathematicians, like most human beings, have weak minds and need methods "in which the imaginative faculty plays a greater part than their power of reasoning." (*ibid.*). But when a mathematician resorts to the manipulations of geometric diagrams or algebraic symbols, is he simply holding concrete objects in his imagination? Is the travesty not Duhem's comparison of the use of the mathematical imagination with the prodigious memory for facts and localities of Napoleon (A 57-60)? Is there no scope for a disciplined mind to follow the consequences of no more and no less than what its actions (real or hypothesized) have embodied in a medium however sensuous or concrete? Is this not a form of the very exercise of intelligence whose virtues Duhem extols (A 55), viz. abstraction and generalization? The diagram is after all considered in *abstraction* from any circumstance which does not bear upon the possibility of, or the results of carrying out, a construction of that *general* kind.

Is there not a danger in insisting, like a latter-day Plato, that mathematical physicists must reason only about objects which are not physically realizable (abstract lines of force, material points, equipotential surfaces, A 69-70)? Does this approach not create unnecessary puzzles about how pure mathematical reasoning bears any connection to physical reality? The Aristotelian antidote to such problems is to recognize that the Very Object of the mathematician's, or the mathematical physicist's investigation is capable of concrete embodiment. With the help of Kant we can elaborate this Aristotelian approach to account for the peculiar rigour and certainty which pure mathematics attains without capitulating (as did Aristotle) to Platonism in the form of "intelligible matter" (e.g. *Metaphysics* VII.10, 1036a9-13). The pure mathematician studies only what he has put (hypothesized) in the object of his investigation; the hypotheses from which he draws necessary conclusions have the linguistic force of imperatives, are rules or precepts. It is left to the mathematical physicist to consider how this construction answers to experimental observation.

Where Kant strayed, according to Peirce, was in thinking that he had distinguished mathematics from other forms of necessary reasoning. Lacking an adequate logical treatment of relations Kant failed to see that,

> All necessary reasoning whatsoever proceeds by construction; and the only difference between mathematical and philosophical necessary deductions is that the latter are so excessively simple that the construction attracts no attention and is overlooked. The construction exists in the simplest syllogism in Barbara. (3.560)

Although this claim carries the dispute to the very heart of Duhem's position, it broaches a subject, the grounds of the validity of deductive logic, which Duhem does not address and which is too vast and too far from the concerns of this paper to be treated adequately. But Peirce's enthusiasm for the logic diagrams, which were pioneered by John Venn and Lewis Carroll and his own efforts to generalize such devices point to a weaker claim which tells against Duhem, and which can be succinctly put: Even if some deductive steps do not employ iconic devices, should it be forbidden to use them in the development of a logical theory?

Duhem would doubtless see such diagrams as a concession to weak minds, but is it not possible to *reason* with perfect rigour over the construction of a Venn diagram so as to establish with perfect *generality* the validity of an unobvious syllogism? There is, to be sure, a call upon an exercise of the mind, which it is not unnatural to call imaginative, in order to grasp how it is that three overlapping circles can represent exhaustively all that can be said about an object in some universe of discourse using exactly three terms, and how marking this diagram can express precisely the content of a general categorical proposition. But if this requires an exercise of the imagination, does that make it less than rational? And is it not obvious that a failure to use the imagination in this way can cripple one's reasoning ability?

The burden of at least part of Duhem's arguments against regarding models as constituents of scientific theories was that as products of imaginative activity they are flawed material; one cannot have imaginative constituents in a theory any more than one can have a saw made out of wood. Peirce, drawing on elements of the Aristotelian and Kantian traditions would claim to have identified an alloy of reason and imagination, which is not only suitable for building theories, but is essential for their full development. Where Duhem contended that the products of the imagination are concrete and obstruct the process of generalization, Peirce drawing on Kant argued that the concrete can be viewed abstractly and dealt with purely in terms of the *general* conditions of its construction. Where Duhem insisted that models could not unify phenomena, Peirce argued in an Aristotelian spirit, that as one can find a structure, the Very Object of one's investigation, in a multitude of concrete phenomena, so one can find it in a concrete diagram. Where Duhem might argue that the exercise of imagination is a private, subjective activity, reflecting the individual peculiarities of this or that human being, Peirce would argue that the precepts for the construction of a diagram in a concrete sensuous medium are universal, recognizable as fulfilled or unfulfilled, and recognizable as having certain necessary consequences, by all rational creatures.

III. Representing Reality

As the dispute has unfolded, our attention up to this point has tended to focus on questions about "strength (rigour) of material." But whether a certain mental activity and its vehicles are suitable constituents of (respectively) scientific theorizing and its products is a question which also depends on how one conceives the function (or Aristotelian 'final cause') of scientific theories. Duhem might still resist claims made on behalf of an alloy of reason and imagination because of the way he conceives of the *aim* of physical theory. Indeed, does not Peirce accept, while Duhem rejects, the idea that the aim of science is to 'explain'?

The difference here turns out to be more one of words than one of substance. By 'explain' Duhem means "strip reality of the appearances covering it like a veil, in order to see the bare reality itself" (A 7). Peirce, however, is wholly unsympathetic to any metaphysical picture which places appearance and reality in this kind of global contrast. According to Peirce, we call for explanation "when facts contrary to what we should expect emerge" and what we are asking for is simply "such a proposition as would lead to the prediction of the observed facts" (7.202). Duhem himself recognizes and endorses the procedure, characteristic of Peirce's conception of science, by which one adopts hypotheses, from which it is possible to deduce a statement describing some observed state of affairs (such as an experimental law). Deductivists who have come after Duhem have not been reluctant to use the word 'explain' so long as it applies strictly to deducing from general principles.

Duhem insists (A 19) that *rather than* explain (as he understands the word) theories should be taken to 'represent.' Here Duhem and Peirce would appear to agree, for Peirce would certainly have classified theories as representations, but this verbal agreement marks a profound difference. It is not, however, a straight-forward matter to make this difference clear, for while Peirce invested a great deal of effort in developing a comprehensive and rigourous theory of representation, Duhem takes the concept for granted, assuming that it is perfectly clear what it is for something, in particular a theory, to represent. All we have to go on is the way Duhem contrasts (A 26) the illusory explanatory use of a concept such as that of luminous vibration with its correct use as a representation. In the former case the physicist is led to think of a real to-and-fro motion of a real body (the ether), whereas in the latter case he considers only a "pure geometric expression – a periodically variable length" which helps to state hypotheses by which he "regains" through "regular calculations" experimental laws governing light. "This vibration is to our mind a representation not an explanation" (*ibid.*). The physicist's theory serves "only to give experimental laws a summary and classificatory representation" (A 27).

This use of 'represent' would clearly fit under the wide umbrella, which Peirce unfurled as his entry for that verb in Baldwin's *Dictionary*[7],

> To stand for, that is, to be in such a relation to another that for certain purposes it is treated by some mind as if it were that other. (2.273)

This entry, however, taken on its own would leave the impression that to grasp what it is for something, a sign or 'representamen',[8] to represent, all one needs is to grasp a two term relation between it and what it represents or signifies. There is nothing in Duhem's use of the concept which would suggest the inadequacy of this impression, but all of Peirce's detailed writing on the theory of signs (semiotics) stress the need for a more elaborate basis. For example,

> A sign, or *representamen*, is something which stands to somebody for something in some respect or capacity. It addresses somebody, that is, creates in the mind of that person an equivalent, or perhaps more developed sign. That sign, which it creates I call the *interpretant* of the first sign. The sign stands for something, its *object*. It stands for that object, not in all respects, but in reference to . . . the *ground* of the representamen. (2.228)

Peirce held that something is a sign as soon as it is capable of functioning as a sign whether it ever actually does so or not (2.275) and that three general conditions (or "*grounds*"[9]) give a thing this capability. One is some feature which the sign has in its own right, so that it may bear a similarity to a thing (which would be its object). The second is some causal relation in which the sign stands to its object and the third is a general law or habit governing a mind to move from the sign to an Interpretant (the equivalent or more developed sign referred to in 2.228).

It is the first condition which concerns us here for whatever a sign has in its own right which enables it to function as a sign renders it iconic (2.276). Iconic signs (or 'hypoicons') can be of three sorts. If they partake of the same simple quality as their objects, they are *images*; if there is a relation between their parts analogous to those of their object, they are *diagrams*; and if they "represent the representative character of a [sign][10] by representing a parallelism in something else [they] are *metaphors*" (2.277). It might seem from the arguments considered in Section II above that what separates Duhem and Peirce is simply that the former was prone to treat all icons as images and thereby misunderstood the function of the second sort, diagrams. But a consideration of the third sort of icon, what Peirce calls 'metaphor,' will reveal a further dimension to the gap between Duhem and Peirce.

When Johnny Morris[11] claims (his) memory is a green pond, he is using a parallelism between the way things disappear beneath the surface of an algae covered pond until dredged up by something acting on the pond and the way the contents of (his) memory are not manifest until something "stirs" it. According to Peirce's definition the parallelism "represents the representative character of a [sign]." (His) memory is the object Johnny Morris has represented, to himself and to his audience, by a sign, and that sign must determine another, perhaps more developed sign, its 'interpretant.' One development of the sign '[J.M.'s] memory' is 'a container with an astonishing capacity, only a tiny proportion of the contents of which are manifest at any one time, and requiring external stimulus to make individual items manifest.' It is this part of the character of the sign, viz. its correlation to some of indefinitely many equivalent or more developed signs, which is what the image of the green pond represents.

Note that when an icon, of the sort which Peirce calls a diagram, is used in physical (or natural), as opposed to mathematical, science, it shares this feature with the image of the green pond; for it represents a parallelism between its manifest character (or developable consequences) and a way of interpreting a sign for some natural phenomenon. Such a sign might be the formulation of one of Duhem's 'experimental laws', for example the Boyle-Charles law. Statistical mechanics, using various diagramatic devices to represent the behaviour of aggregates of gas particles, has provided us with an interpretation of that law. This is why it is natural to say that an explanatory theory, if successful, tells us what an experimental law means.

Now as it proved extraordinarily difficult to develop the sign '[J.M.'s] memory' in strictly non-metaphorical language (witness: 'container', 'capacity', 'contents'), there *may be no immediate* way to develop the signs for a natural phenomenon in any way except via such a parallelism. The model-as-metaphor may be our only way to acquire a language in which to represent phenomena in their full complexity and inter-relatedness. Peirce's theory thus contains an anticipation of the doctrine advanced a few decades ago by Max Black[12] that models in science play a role similar to that of metaphors in poetic and rhetorical discourse.

Any fully worked out justification of the use of (Peircean) diagrams in the natural sciences, in other words any justification of the use of models as (Peircean) metaphors, to come out of Peirce's philosophy will rest a great deal of weight on Kant's notion of the productive imagination. But it will place an even greater weight on the requirement that signs have interpretants – interpretants which are signs determining further interpretants in endless chains.[13] And it is very probable that here is what most divides Peirce's philosophy from that of Duhem. It is hard to be certain, for Duhem, as we've noted, takes a great deal for granted when he appeals to the notion of representation in science. What is clear, at least, is that some of the consequences of Peirce's doctrine of signs are diametrically opposed to the way Duhem conceives science and its metaphysical framework.

One crucial consequence of Peirce's doctrine is that what we think of as the objects, (including events, laws, etc.) to which our signs refer, depends on the way we interpret the signs we use. Different habits of interpretation, different ways of moving from sign to (a perhaps more developed) sign, will alter what objects are represented in our thought. This means that the function of science cannot be *simply* that of reclassifying phenomena, for phenomena are repressented in our thoughts; and as our ways of interpreting such signs alter, so will the objects we have to classify.

Another closely related consequence follows from linking this account of signs to Peirce's thesis that all thinking is in signs (all thought requires a vehicle). There can be nothing in thought, neither experience nor reality which is not a sign, and in need of an interpretant. Early in his career (5.310-317) Peirce combined these two doctrines, viz. that all thinking is in signs and that all signs must have interpretants, and made it his own basis for a departure from Kant which was made by many others in the nineteenth century, who regarded Kant's thought as a watershed. Peirce drew the conclusion that the thing-in-itself, the object of thought independent of all cognition is an incoherent notion. It results from an impulse to treat the object of thought as though it could enter thought without the mediation of signs, without being represented by something, which stands in need of interpretation. Does this mean that for Peirce science can never grasp physical reality? Far from it. The account of reality which Peirce favoured was (roughly) 'what is represented in the best possible system of signs, which the efforts of natural scientists are (ever will be) capable of producing.' Reality for Peirce was the final cause, not a hidden (inaccessible) efficient cause of our representations.

An inaccessible physical reality haunts Duhem's account of science. He writes of "the kindred relations among substances themselves, whose nature remains deeply hidden, but whose reality does not seem doubtful" (A 29). The physicist, as Duhem depicts him, is constantly tempted to "assert his faith in a real order reflected in his theories," but is cautioned that he "cannot take account of this conviction. The method at his disposal is limited to the data of observation" (A 27). Duhem does not question the coherence of this conception of reality; it seems to be a necessary structural feature of his Roman Catholicism (see Appendix to A). Clearly one of his motives is to keep the images of nature, which science generates and which feed materialism, from competing for the imaginations, and thereby the hearts, of believers. His philosophy of science affords him a two-prong strategy for this purpose: distance materialist images from science proper and distance science from any pretense to deal with physical reality.

A scientific realist, of the sort defended in Harré's philosophy of science, claims that the models of nature, which science generates, represent reality as it is, and thereby offers us the sort of explantions which Duhem declared to be impossible. As long as such a realist shares Duhem's conception of reality and the way it is represented in our thought, he faces a sceptical challenge from Duhem. What possible reason can there be for thinking that the figments of our imagination, far from penetrating to reality itself, do anything more than weave a layer of illusion over appearances? Even in the case of his most tested and best performing theories the physical scientist is only,

> Yielding to an illusion which Pascal would have recognized as one of those reasons of the heart "that reason does not know," [when he] asserts his faith in a real order reflected in his theories more clearly and more faithfully as time goes on. (A 27)

Under Peirce's conception of thought as necessarily embodied in a medium of signs and his conception of signs as necessarily determining an endless series of interpretations, the modeling or diagramatic representation of nature is an indispensable organ of science in pursuit of its legitimate goal. Its goal is reality, not a reality which stands outside the theoretical representations of science and mocks our efforts to reach it, nor a reality which must in some mysterious way be present itself in our theories without betraying its nature as extracognitive and thereby ceasing to be reality. The goal of science is the representation of reality, which is what the system of signs, which constitutes what science would be, should it complete itself.

Now this too requires faith, not faith in the sense of a belief in some Great Fact transcending human powers of reasoned thought, but faith in the sense of a commitment to the use of such powers, a confidence that they can fulfill themselves if set to work, and a belief that it is worthwhile to contribute to the realization of something Peirce called "concrete reasonableness." This may also be a "reason of the heart", but it is one in which reason finds itself.

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NOTES

1. Rom Harré, *The Principles of Scientific Thinking*, London, Macmillan, 1970, p. 13. References to this book will be given hereafter in the text marked by an upper case 'P' and the page number.

2. Pierre Duhem, *The Aim and Structure of Physical Theory*, Philip P. Wiener, Trans., New York, Atheneum, 1962, p. 103. References to this book will hereafter be given in the text marked by an upper case 'A' and the page number.

3. Cp. Mary Hesse, *Models and Analogies in Science*, Notre Dame, Indiana, University of Notre Dame Press, 1970, pp. 26-42.

4. Peirce was senior by twenty-two years but died in 1914 only two years before Duhem.

5. "Prolegomena to an Apology for Pragmatism", *Monist* 1906. References to Peirce's writings here and in the text to follow are to *The Collected Papers of Charles Sanders Peirce*, eight volumes, edited by Charles Hartshorne, Paul Weiss and Arthur W. Burks, Cambridge, Massachusetts, Harvard University Press, 1931-1958. They take the customary form of a decimal, referring to volume and paragraph. This article begins at 4.530.

6. That this is the peculiarity of mathematical reasoning was, Peirce argues, discerned correctly by Kant in the Transcendental Doctrine of Method, Chapter 1, Section 1 (*Critique of Pure Reason* A712-766). Kant held that mathematics reasons about 'constructions', the generic term for which Peirce says, is 'diagram'. "Such a construction is formed according to a precept furnished by the hypothesis," (3.560) and this is the correct context in which to understand the essentially equivalent definitions of mathematics as "the science which draws necessary conclusions" (offered by his father, the mathematician Benjamin Peirce) and the science which proceeds from "pure hypotheses" (George Chrystal) (3.558). The hypothesis from which the necessary conclusion may

be drawn has the linguistic force of an imperative; it is a rule or precept.

7. James Mark Baldwin, ed. *Dictionary of Philosophy and Psychology*, New York and London, Macmillan, 1901, Vol. 2 p. 464.

8. The entry in Baldwin's *Dictionary* goes on to recommend that the noun 'representation' be reserved for the "act or relation of representing" and proposes 'representamen' for "that which represents." Elsewhere Peirce uses 'sign' as interchangeable with 'representamen' (in other words for what, following Harré, has here been referred to as a 'vehicle of thought'.). In the manuscript that is the source of 2.274, however, Peirce generalizes 'represent' so that it does not necessarily involve a mind and then restricts 'sign' to 'representamen with a mental Interpretant.' Peirce does not, however, appear completely confident that a representamen which is not a sign is a real possiblity; "... possibly there may be...," he says.

9. That this is the correct interpretation depends on my having correctly threaded my way through the labyrinthine syntax of 1.551-8.

10. To tone down the mesmeric quality of this passage I have here and below substituted '[sign]' for 'representamen.' See note n. 8.

11. BBC Radio 4; 1815-1830 GMT, 30th December 1986.

12. Max Black, *Models and Metaphors*, Ithaca, New York, Cornell University Press, 1962, pp. 219-43. By virtue of a common Kantian source of inspiration, Peirce also anticipates the role assigned to the productive imagination in Paul Ricoeur's account of "the metaphorical process." See "The Metaphorical Process as Cognition, Imagination, and Feeling," in Sheldon Sacks, ed. *On Metaphor*, Chicago, The University of Chicago Press, 1978, pp. 141-157.

13. Cf. Peirce's entry for 'sign' in Baldwin's *Dictionary* (2.303): "Anything which determines something else (its *interpretant*) to refer to an object to which itself refers (its *object*) in the same way, the interpretant becoming in turn a sign, and so on *ad infinitum*.

"No doubt, intelligent consciousness must enter into the series. If the series of successive interpretants comes to an end, the sign is thereby rendered imperfect, at least. If, an interpretant idea having been determined in an individual consciousness, it determines no outward sign, but that consciousness becomes annihilated, or otherwise loses all memory or other significant effect of the sign, it becomes absolutely undiscoverable that there ever was such an idea in that consciousness; and in that case it is difficult to see how it could have any meaning to say that the consciousness ever had the idea, since the saying so would be an interpretant of that idea" (Cf. also 2.92).