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Models, scientific realism, the intelligibility of nature, and their cultural significance

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ABSTRACT

In this article, I will view realist and non-realist accounts of scientific models within the larger context of the cultural significance of scientific knowledge. I begin by looking at the historical context and origins of the problem of scientific realism, and claim that it is originally of cultural and not only philosophical, significance. The cultural significance of debates on the epistemological status of scientific models is then related to the question of 'intelligibility' and how science, through models, can give us knowledge of the world by presenting us with an 'intelligible account/picture of the world', thus fulfilling its cultural-epistemic role. Realists typically assert that science can perform this role, while non-realists deny this. The various strategies adopted by realists and non-realists in making good their respective claims, is then traced to their cultural motivations. Finally I discuss the cultural implications of adopting realist or non-realist views of models through a discussion of the views of Rorty, Gellner, Van Fraassen and Clifford Hooker on the cultural significance of scientific knowledge.

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1. Introduction

My aim in looking at models in science is really motivated by larger interests concerning science, to which an examination of models would give a sharper focus. For example, questions concerning the epistemological status of scientific theories can be more clearly seen through an examination of models, which have been given interpretations by both realists and non-realists. Similarly issues concerning science's attempt to give us an 'intelligible view or account' of the world can best be treated by looking at models to which the notion of 'intelligibility' can be attached. In other words, philosophical questions concerning 'scientific knowledge' can be more clearly articulated and tackled by looking at models, which admittedly form part of scientific theories (Leatherdale, 1974). I will begin by laying out the historical context of scientific realism before looking at both realist and non-realist arguments and perspectives on models, and relate them to the issue of 'intelligibility' in science. Finally, I will attempt to discuss the cultural implications and significance of adopting either realist or non-realist views of scientific models.

Realists are largely representationalists who view models as representations of physical reality. Typically, they also adopt the correspondence theory of truth. Scientific models are therefore seen as attempted descriptions of physical reality. Tied with this idea is the idea of 'intelligibility', which is sometimes construed in terms of 'visualizability' (Miller, 1981; Gilman, 1992). Typical examples would be nineteenth century theories in physics and chemistry which look at the behavior of matter in terms of atoms, and the theory of chemical reactions which appeal to atomic configurations. Although the scientific model involving atoms, electrons, genes etc., refer to the 'unobservable' which is supposedly responsible for the behavior of the phenomenal world, the 'language' used in describing them does not significantly depart from the language one would use in describing phenomena at the level of the 'macro world'. This 'linguistic continuity' across the two domains, i.e. the macro-observable and the micro-unobservable, serves to maintain a sense of 'intelligibility' and also provide credence to the realist's account of the physical world. Another feature of the realist's account is their reliance on a 'substantive' or 'pictorial' view of models, as opposed to a mathematical or formal view. Brian Ellis (1985:52) describes this as 'a commitment to a physicalist ontology'. Again this is related to the intuitive idea of 'intelligibility of the physical world', in which we understand physical events and processes as taking place among and through the

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interactions of substantive physical objects. Admittedly this is an Aristotelian as opposed to a Platonic or Pythagorean view of the world. Another item in the realist's repertoire is the appeal to modalities such as 'physical causation'. All these features which I have described, perhaps fit in with a sort of 'physical realism' as opposed to 'structural realism'. But physical realism seems to be the more 'common' sort of realism and carries more interesting epistemological and cultural implications. Scientific realism as physical realism, in which models are construed through those characteristics or parameters, have of course been subjected to criticism. One important criticism has been made by Laudan (1981) in his 'Confutation of Convergent Realism'.

The scientific realist account of models also has another interesting perhaps non-cognitive, and even emotive aspect, i.e an ontological commitment to certain metaphysics or archetypes as in Holton's themata or Kuhn's paradigm, which is made possible by the idea that models represent. In other words, representation carries with it not only reference, but concomitantly also 'sense'. To adopt a certain model is to adopt a certain 'emotional' stance towards the model. Realism might be a 'natural ontological attitude' to borrow Fine's phrase, but to those averse to the 'sense' contained or implied by the model, the attitude can be revised or modified.

Opposed to realist accounts of models are the non-realist or anti-realist view of models which have taken several forms, for example instrumentalism, constructive empiricism and pragmatism. Anti-realists deny that models give a true description of physical reality, especially in terms of its ontology. Instead they interpret models as instruments of prediction (instrumentalism), symbolic representations of empirical phenomena (constructive empiricism), or conceptual and/or artifactual devices utilized within the network of actions or activities in the production of scientific knowledge (pragmatism). As such the non-realist deny the epistemological role of models in giving us a causal explanation of physical reality. Related to the non- or anti-realist view of models are certain motivations and cultural implications which are not strictly speaking, within the ambit of the cognitive or of analytic philosophy of science. It is more to do with the question of the cultural role of scientific knowledge. It is from this perspective that I would like to approach the issue of realist and non-realist interpretation of models, i.e. in terms of its cultural significance.

The present debates between realism and anti-realism, and between realist and anti-realist interpretations of scientific models, have often been presented within the framework of analytic philosophy of science (Losee, 2001: 252-263). The present essay however, attempts to look at the issue in terms of the cultural role of scientific knowledge. What are the cultural implications of realist and non-realist interpretations of models? I will try to show that the problem of scientific realism has historical and cultural roots and that it can be understood as such, and not purely in terms of analytic philosophy of science (Shah, 2003). Contemporary discussions of models and scientific realism in the philosophy of science have lost sight of, and obscured the origins and context from which the issues rose, and of its cultural bearings. My task in this essay is to uncover the historical origins of the issue of scientific realism, and its cultural significance. The cultural significance of the issues surrounding models and scientific realism will be shown not only to have occurred in the historical past, but that it remains with us today. To facilitate this task, before examining realist and non-realist accounts of models, I will trace some of the salient developments in the historical evolution of science in order to provide an understanding of the historical context which gave rise to the problem of scientific realism, and consequently, conflicting appraisals of the epistemological status of scientific models.

2. Models and scientific realism: Historical context and origins

Debates on scientific realism has had a long history; it stretches not only as far back to the 17th century with instrumentalist versus realist accounts of the Copernican model in the history of astronomy, but also with similar controversies in the history of medieval astronomy particularly in the interpretation of the status of the Aristotelian crystalline spheres. In fact the phrase 'saving the phenomena', which is often cited in contemporary debates on scientific realism, originated from such medieval discourses. In this section, I would like to appeal to history in helping to provide a perspective on the issue of scientific realism. This will take two forms: (i) a more specific historical case involving the 17th century controversy in the history of astronomy between realist supporters of the Copernican model and their instrumentalist opponents, and (ii) a more general historical account involving the transformation from natural philosophy to natural or modern science, and how it set the scene for some of the issues on scientific realism. Both accounts will help us see the cultural significance of the issue of models and scientific realism.

2.1. Instrumentalist versus realist interpretations of the copernican model in 17th century astronomy

That scientific realism really has historical roots and cultural significance can be seen by looking at the episode in the history of 17th century astronomy involving the conflict between Galileo and the Roman Catholic Church. In his article 'Three Views Concerning Human Knowledge' (Popper, 1972: 97–119), Karl Popper reminds us that the present debates on scientific realism which is often presented in a clinical and analytic fashion, devoid of history and cultural significance, is a mask that needs to be unveiled so that analytic philosophy of science could remain relevant to broader cultural issues as philosophy did in the past.

There are certain interesting features in the controversy over Galileo's advocacy of the Copernican model, which can be related to, and perhaps shed light on, contemporary debates on scientific realism. These features are:

i. an opposition between realist and instrumentalist interpretations to the Copernican model,
ii. a passionate, emotive and psychological reaction to both the Ptolemaic and Copernican models, and the question of sense and reference
iii. the wider cultural (in this case religious) significance of the debate on scientific realism and the Copernican model.

As we will see, some of these features later re-appear in contemporary debates on scientific realism. Today only (i) stands out as having a clear analogue in current debates on scientific realism, i.e. the interpretation concerning the epistemological status of the models. (ii) and (iii) do not seem to clearly feature in contemporary discussions on models and scientific realism. However, I will try to show how features (ii) and (iii) are also present, albeit in an attenuated or masked form. Looking at the controversy surrounding the Copernican model is advantageous in that it clearly exhibits all three features. Because of the different nature of contemporary society, the wider cultural implications of the debates on scientific realism will not be obvious. Neither will something like 'psychological commitment' or 'aesthetic preference' for a model become an issue, since that is within the realm of the context of discovery rather than justification, even though Holton's (1988) analysis of 'themata' in science suggests the importance of scientists' psychological commitment to themata in theory-choice.

In the debate, Galileo adopted a realist position with respect to the Copernican model while the Roman Catholic Church took an instrumentalist position (Popper, 1972). The Church however, did not object to realism *per se*—after all, treating either the Ptolemaic or Tychonic model in a realistic manner was deemed to be consistent with the teachings of the Bible. So here we have a case where an 'instrumentalist' position with regard to the Copernican model, coupled with Jesuit support for the Tychonic model in the face of Galileo's telescopic evidence, can be seen as a logical strategy of 'deflecting' the impact of the evidential force of the Copernican model. I want to argue that scientific knowledge through scientific models, has the capability of providing cultural and social impact, which draws several types of responses. In this particular case, two types of responses can be identified, namely: (i) proposing an alternative scientific, i.e. astronomical theory (which can however, be interpreted in a realist sense) in the form of the Tychonic model where the planets revolve around the sun but the sun and the planets in turn, revolve around the earth, i.e. a 'compromise model', and (ii) proposing an instrumentalist interpretation to the Copernican model. The first type of response is a 'scientific response' involving the formulation of an alternative theory consistent with one's metaphysical belief. The second type of response is a 'philosophical response' which rejects a realist interpretation and hence avoids cognitive and ontological commitment to the model/theory. Through gradual consolidation and elimination of *scientific* alternatives in the course of the history of science the philosophical response eventually becomes the only option for those who want to avoid or 'deflect' the hegemony of an unpalatable scientific world-picture.

2.2. The transformation from natural philosophy to natural science and its implications for the status and role of scientific knowledge

In order to gain some understanding of why models pose a problem for scientific realism, we need to go back to the history of science and retrace certain steps in the historical evolution of science. In rough schematic terms, these steps are:

i. the initial separation between natural philosophy, mathematics, and the exact sciences
ii. the merger between natural philosophy and mathematics, and the question of the nature of causation
iii. the rise of the experimental method and the practical application of scientific concepts and models to nature.

Before the 17th century science, *natural philosophy* continued largely in the tradition of Greek science which exerted its influence in the Middle Ages (Grant, 1996). Science as episteme and natural philosophy sought to provide an understanding of the natural world and served mainly a cognitive, intellectual function. What separated natural philosophy from mathematics and the exact sciences such as astronomy or statics was the fact that natural philosophy was thought to give a *causal* explanation of natural phenomena, while the exact sciences such as astronomy merely gave a descriptive account of phenomena and that mathematics presented purely logical or functional relations (Gaukroger, 2006; Grant, 2007). Natural philosophy could only be accepted or understood as a 'science' because it offered a causal understanding of nature. Galileo exemplified a trend towards the mathematicization of natural philosophy with his study of falling bodies seeking to find the mathematical relationship which govern their behavior. The mathematical analysis of the physical world was further laid on a strong foundation by Isaac Newton in his book with the rather telling title of *Mathematical Principles of Natural Philosophy* (Dear, 1998). The title though, is somewhat of an oxymoron since mathematical principles were not usually thought of as giving us the 'why' or 'cause' of things, which is what natural philosophy sought to provide.

The 17th century with its combination of natural philosophy, mathematics and the experimental method led to a new criterion of scientific acceptance, and by implication, of rejection: For a scientific theory to be accepted it must be 'operational' and pass experimental tests. No longer did a scientific theory purely serve the function of providing a rational understanding of nature. Without such a criterion the debates about scientific realism and the epistemological status of scientific theories would not be conceivable. The success of a theory, as measured by explanatory and predictive success, in turn came to be seen as a sign of its ontological truth. An early quotation from Francis Bacon relates practical success with the truth or veracity of the model or theory quite directly:

> Now although it be true, and I know it well, that there is an intercourse between causes and effects, so as both these knowledges, speculative and operative, have a great connexion between themselves; yet because all true and fruitful natural philosophy hath a double scale or ladder, ascendent and descendent, ascending from experiments to the invention of causes, and descending from causes to the invention of new experiments; therefore I judge it most requisite that these two parts be severally considered and handled. [As quoted in Peter Dear, 2005:395]

For Bacon, the 'effect', i.e. the confirmation of the theoretical prediction, proved the existence and the truth of the 'cause', exemplified by the explanatory model. In other words, the utilitarian nature of science, and the fact that 'science works', is taken as evidence for the truth of its explanatory concepts, which includes pictorial models. Thus the 'causal ghost' of Aristotelian natural philosophy re-emerged even with the emergence of modern science and its integration of natural philosophy, mathematics and the experimental method. Modern science, in this mode becomes both epistemic and causal once more, as well as realist.

The conjoining of natural philosophy with mathematics and experimentation carries with it an 'inherent inner tension' which was later manifested partly through controversies on the epistemological status of scientific theories and models. The tension inherent in such fusion is due to the fact that the elements conjoined have different aims; as natural philosophy or 'episteme' it seeks to provide knowledge or 'truth' about the natural world, as (descriptive) mathematics and experiment—collectively associated with 'techne'—it seeks to be operational and functional. Francis Bacon tried to defuse the tension by having workability as a sign of truth. As Peter Dear (2005) has correctly observed, the empirical confirmation of the theory/model was then taken as a confirmation of the truth of the causal mechanism postulated by the theory/model.

Another consequence of the integration was the rejection of theories that are non-operational or that failed experimental tests, and the acceptance of operational theories that pass experimental tests. Given the realist interpretation of accepted theories such as the one presented by Bacon above, this implies that 'paradigmatic pluralism'—the existence of different fundamental approaches to the world—has become a thing of the past and that the hegemony of the scientific world-view now asserts itself through such 'paradigmatic monism'. Again, this methodological change in the historical evolution of science implies that resistance to the dominant scientific world-picture subsequently could only be effected through philosophical responses since truly fundamental alternatives were no longer entertained. Exceptions occur only in rare cases when (different sets of) experimental evidence exist in support of more than one theory, such as the wave and particle theories of light.

3. Realist and non-realist accounts of models and the decline of scientific realism

The debate between realists and non-realists has been a long standing affair. Basically, realists want to argue that the theoretical entities postulated in scientific theories really exist, i.e. that the theoretical terms actually refer, and that scientific theories give a literally true description of the physical world, i.e. that scientific theories are to be taken as literally true. The non-realists, be they instrumentalists, constructive empiricists or pragmatists deny both those claims. That is, they deny that theoretical terms such as 'atom' actually refer, and they deny that theoretical statements have truth-values. Given such denials, non-realists are then presented with the task of explaining the relationship between theoretical terms and statements, and observable phenomena. Two non-realist approaches have gained prominence in the recent debates on scientific realism, namely: (i) the constructive empiricism of Bas van Fraassen, and (ii) pragmatist accounts given by Giere (2004), Nersessian (2006) and Knuuttila (2005). For Van Fraassen, theories can be accepted as true in the sense that they are 'empirically adequate'. Thus the atomic theory, insofar as it 'saves the phenomena' can be accepted as a 'true theory', but he falls short of accepting the realist argument in terms of 'inference to the best explanation' and of claiming that atoms—as depicted through models—actually exist, or that what the atomic theory says about the motions and interactions of atoms, is literally true. The pragmatists on the other hand, emphasise the *use* to which models are put, i.e. its functional role within a network of socio-cognitive practices. For Knuuttila for example, models are to be looked at in terms of the *means of representation*, which involve a set of practices, rather than standing in a relationship between the represented (physical reality) and its representation (model).

What is at issue in these controversies between the realists and non-realists, is, in a manner of speaking, the question of whether there exists one world, i.e. the world of observable phenomena, or two worlds, the world of observable phenomena and that of unobservable phenomena which is best described via scientific models and theories.

Now in order to understand the realist position better, let us recall some of the main features of the realist position in relation to models:

(1) It postulates a physicalist ontology that has as its corollary a commitment to the idea of models as substantive and pictorial in nature, as opposed to being 'merely' formal or mathematical. A substantive and pictorial model appears more intelligible with respect to our usual understanding of the macroscopic world, as compared to an abstract mathematical model.
(2) A 'semantic continuity' across the macroscopic and microscopic worlds whereby talk in terms of the macroscopic 'carries over' to the microscopic; more often than not, this is based on the assumption that unobservable entities in the micro-world are causally responsible for what is found in the observable world.
(3) The idea of models as *representing* physical reality, although the representation might be partial rather than 'complete', in that it only captures certain (structural) features of it. Here pictorial models are to be understood literally, in which there exists an isomorphism or a one-to-one correspondence between the theoretical-pictorial model and the unobservable micro-entity.
(4) The idea that theory-change, and by implication the succession of models associated with the respective theories, leads closer and closer to the truth: science is converging to a more faithful description of physical reality—just as it should, according to scientific realists.
(5) A commitment to the idea of science as *episteme*, i.e., as being in the business of giving us knowledge about physical reality: experimental confirmation really *is* confirmation of the underlying causal mechanism postulated by the theory (Boyd, 1973).

Some of the ideas presented above, such asthe idea of 'ontological convergence' implied in (4), have been criticized, for example by Kuhn (1970) and Laudan (1981). What I want to touch on at this stage, is the relative strength of both positions, and the cultural implication of accepting either the realist or non-realist point of view. Prior to Bas van Fraassen's constructive empiricism, and pragmatist accounts of science, scientific realism was the dominant philosophical account of models and theories (see Rouse, 1998), and was often coupled with a form of physicalism. Our understanding of the natural world is to be reduced to what physics tells us, and the story that physicists tell us is to be accepted as 'literally true'. In this account which physics tells us, 'intelligibility' still has to be maintained, in the sense that physical explanation must satisfy our intuitive notions of what an 'explanation' involves, such as physical causation.[1] Thus Nancy Cartwright (1983) in her book, *How the Laws of Physics Lie*, insists that physics must include causation and that the world should be understood in an 'Aristotelian' sense, i.e. that the intelligibility of the macroscopic physical world be maintained.

However, two important developments that have since occurred have challenged this view of science presented by the scientific realists. The first is the trend, exemplified by quantum mechanics, towards mathematical formalism as opposed to pictorial models (Schrödinger, 1996). This has a bearing on our points (1) and (2). For realists, there is a continuity between the language of the macroscopic world and language of the microscopic world. This linguistic or semantic continuity is important in order to make good the realist claim that 'science aims to give us a true picture of the world'. Unless the statements of scientific theories are meaningful, they cannot have a truth-value. Our idea of what is meaningful and intelligible derives from our interactions in the ordinary everyday observable world; a world in which we make sense of physical events in terms of objects in motion, colliding, pushing and pulling one another in space. With the advent of quantum mechanics, this can no longer be maintained, with the result that some—for example Worrall (1989), Ladyman (1998) and Zahar (2007)—have turned to *structural realism*, in response to the difficulties associated with a physical ontology realism.

The second important development which has a bearing on the issue is the emergence of a so-called 'technoscience', which affects both the nature of the organization of scientific work, as well as the nature of scientific knowledge. Whereas before, the idea of pure science existed as an important and independent entity, and the claim that science aims at knowledge can guide scientific practice, today science has become more and more enmeshed with technology—so much so that the boundary between 'pure' and 'applied', 'theory' and 'practice', has become blurred. One consequence, I want to suggest, has been that science now becomes more amenable to pragmatist philosophical interpretations (Van Fraassen, 2008). Thus, models need not be seen as standing in a 'representing' relationship in the traditional sense of correspondence—of

[1] See Peter Dear (2003) for an account of the changing sense of 'intelligibility' in science.

models corresponding with physical reality—but instead may be interpreted as 'objects of use'; be it conceptual devices, physical models, or a combination of both. Models are thus seen as part of this wider network of interactions instead of a one-to-one correspondence with the physical world. Meaning is thus to be located within a network of actions rather than in relation to some mind-independent objective reality.

How does the discourse about scientific realism bear on the question of the cultural role and significance of science, and on the question of modernity more generally? It would be hasty to identify scientific realism with scientism and modernity, and anti-realism with a religious or humanist outlook and critique of modernity. Anecdotal evidence is ambiguous on this issue: Although Duhem, who was a devout Catholic, rejected realism because of his religious metaphysics, an earlier French philosopher, Pierre Gassendi, accepted a realist view of atoms even though he was a Catholic priest. Similarly, although the Logical Positivists firmly upheld a union of science and modernity, they rejected scientific realism which they considered to be 'metaphysical'. Looking at the contemporary scene, we find that although on the one hand realists tend to be identified as being 'scientistic' and 'modernist', their appeal to science as 'episteme' seems to suggest a humanist outlook. The antirealists on the other hand, in opposing a realist view of scientific knowledge and promoting an instrumentalist or pragmatist view, seems to leave an epistemic void in modern culture. That is, the realists help us to maintain our sense of familiarity with the world, while the antirealists leave us with a world without understanding, but only empirical facts. As Peter Dear (2006:14) puts it; "Presumed intelligibility is an essential ingredient of natural philosophy, and in that sense natural philosophy is, and always has been, about feeling at home in the world. Perhaps the difficulties that some people find in feeling at home in the modern world are at least in part due to the way that science's instrumentality has increasingly displaced part of that natural-philosophical intelligibility".

4. The substantive/pictorial vs. the mathematical view of models in science

Substantive/pictorial models are contrasted with mathematical models because of the important differences between them, and the implications that follow from those differences. The difference can be understood in terms of the following features supposedly possessed by pictorial but not mathematical models:

1. That it provides for 'intelligibility' in the explanation of natural phenomena, in which such pictorial models are invoked. It satisfies our yearning for 'explanation' of natural phenomena in the sense in which we understand explanation of physical phenomena in the macroscopic world.
2. It gives us a 'causal understanding' of phenomena in the Aristotelian sense of efficient or instrumental cause.
3. It has the potential to evoke certain non-cognitive, emotive or aesthetic response, depending on the picture presented.
4. That pictorial models have a close link with scientific realism, especially 'physical ontology realism', since it purportedly gives us a literally true description or 'picture' of the natural/physical world.

The division of models into pictorial and mathematical can be found in Mary Hesse's (1963) *Models and Analogies in Science*, in which she presents the idea in the form of a dialogue or debate between the Campbellians (after Campbell (1920)) who support pictorial models, and the Duhemians who are against it and are in favour of mathematical models. Duhem's anti-realist motivation, which led him to reject substantive or pictorial models, is perhaps due to his religious commitment and its influence on his physics (see Martin, 1991) Hesse presents the strengths and weaknesses of both positions in the debate. Duhem's rejection of pictorial or substantive models is not so much because of its incapability to give us a 'true picture of the world', but because of his belief that the ultimate true knowledge of the world is to be given through religion and not science. Hesse describes the opposition between the two positions on models thus:

> Duhem's main objection to mechanical models is that they are incoherent and superficial, and tend to distract the mind from the search for logical order ... The ideal physical theory would be a mathematical system with deductive structure similar to Euclid's, unencumbered by extraneous analogies or imaginative representations ... These and similar views were directly challenged by the English physicist N. R. Campbell (whose) main target is the view that models are mere aids to theory construction ... he considers that we be intellectually satisfied by a theory if it is to be an explanation of phenomena, and this satisfaction implies that the theory has an intelligible interpretation in terms of a model ... (Hesse, 1963: 3f.)

Following Friedman (2003) one finds an opposition between the Cassireans (supporters of Ernst Cassirer) and the Meyersonians (supporters of Emile Meyerson) over the question of substantive vs mathematical conceptions in science. The Cassireans are in favour of mathematical models and functional relationships in science (Cassirer, 1978) while the Meyersonians are in favour of substantive models that aim at underlying ontologies. To quote Friedman at some length:

> In the work of Cassirer and Meyerson, then, we find two sharply diverging visions of the history of modern science. For Cassirer, this history is seen as a process of evolving rational purification of our view of nature, as we progress from naively realistic "substantialistic" conceptions, focusing on underlying substances, causes, and mechanisms subsisting "behind" the observable phenomena, to increasingly abstract, purely "functional" conceptions, in which we abandon the search for underlying ontology in favour of ever more precise mathematical representations of phenomena in terms of exactly formulated universal laws ....
>
> ... [Meyerson] by contrast, maintains precisely an ontology of substantial things, and accordingly, it emphatically rejects the attempt to reduce the task of science to the formulation of precise mathematical laws. It ends up with a pessimistic reading of the history of modern science in which our demand for fundamentally ontological rational intelligibility is met by an inevitable resistance to this demand arising from the irrational, essentially temporal character of nature itself (Friedman, 2003: 32f.).

The 'irrationality' which Friedman speaks of, refers, of course, to the changing character of physical objects through time, i.e. the problem of how to assert the identity of an object that undergoes temporal succession.

Both Hesse (1963) and Friedman (2003) contrast advocates of a substantive, ontological view of science (Meyerson/Duhem) and advocates of a non-substantive, mathematical view of science (Cassirer/Campbell). Roughly, while the former are largely realists, the latter are anti-realists. If we start from realism, i.e. a view of science as the search for the true underlying ontology that gives rise to phenomena, we will encounter several possible scenarios. The first scenario, corresponding to the early stage of scientific enquiry where competing ontologies are openly debated, involves a disagreement as to which ontology is acceptable; such disagreement, however, is quite different from the rejection of the idea of ontology itself. The second scenario, which corresponds to the later stage of scientific enquiry, involves a victory of one paradigm over its competitors, and the resulting response from the parties involved. One possible response is for the party whose preferred ontology did not carry the day, to engage in a philosophical re-interpretation in order to avoid a realist acceptance of the ruling ontology. Mach's 'positivism' and his support for a 'phenomenological physics' in opposition to Boltzmann's atomism (Boltzmann, 1974; De Regt, 2005) is an example of such a philosophical response by a scientist. The third scenario involves the philosophical community more than the scientific, although it may shared by the latter. This involves taking an initial philosophical position at the outset, i.e. a realist or an anti-realist position, to ensure that one avoids ontological commitment to any scientific model or theory. This is exemplified by the opposition between realist and antirealist philosophers of science.

5. Philosophical and psychological responses to models

In this Section I would like to discuss the case of models that evoke not only cognitive but also sometimes 'emotive' responses, the most famous of which is perhaps the case of the Copernican vs. the Ptolemaic model in the history of astronomy. Although not all scientific models evoke such strong emotive responses, there are nevertheless cases where they do, and therefore it is important, for anyone wishing to analyse their broader cultural significance, to study the various philosophical attitudes and responses in such cases.

I would like to draw on three very disparate authors—Frege, Feynman, and Holton—to explain by analogy (and thereby throw light on) the issue of the philosophical, emotive, and aesthetic responses to scientific models. Let us begin with Frege's theory of sense and reference. Referring to descriptions, Frege said that two descriptions for example, can have the same referent but different 'sense' or 'meaning' (Geach & Black, 1966: 58–60). For example, the descriptions 'morning star' and 'evening star' both have the same referent, i.e. the planet Venus, although the speaker might not realize that they both refer to the same object. In other words, 'morning star' and 'evening star' carry different meanings or have different sense. Now how does this insight apply to scientific models? Here we can draw an analogy involving two different models, say M_A and M_B, both of which refer to the same target phenomenon D_E. Insofar as they refer to the same empirical phenomenon D_E, we may say that both have the same 'referent'. However, insofar as they carry different ontological pictures, they can be said to have different 'sense'. The case of the Copernican model (M_A) and the Ptolemaic model (M_B) which refer to the same set of celestial objects (D_E) can perhaps be seen in this light. In this case M_A and M_B not only have different 'sense' but evoke strong and opposing emotional responses, perhaps because of its connections with other religious and cultural elements.

Speaking of emotional responses, we can here refer to the somewhat neglected notion of 'themata' in science—which are thought to be manifested or expressed through models—and how they shape scientific work, especially in the context of discovery. The choice of themata, as in Kuhn's account of theory-choice, is not dictated by rational factors, but driven more by philosophical or aesthetic preference. Gerald Holton (1988) explores this dimension in his book *Thematic Origins of Scientific Thought*. For Holton, 'thematic content' of science is a 'dimension that is quite apart from the empirical and analytical content' (Holton, 1988:1), and that 'themata are shown to play a dominant role in the initiation and acceptance or rejection of certain key scientific insights'. Scientists make commitments to their preferred themata and stick by them in their scientific work. Examples of thematic 'couples' given by Holton (1988:17) are: experience and symbolic formalism, complexity and simplicity, reductionism and holism, discontinuity and the continuum, hierarchical structure and unity, the use of mechanism vs teleological or anthropormorphic modes of approach. For example, Heisenberg's adoption of the themata of 'discontinuity/discreteness' and Bohr's acceptance of 'complementarity' and 'indeterminism' (Holton, 1988:116–117). Holton believes that themata occur in the context of discovery and is a motivating factor driving the work of a scientist. Although each themata might have their own empirical success, nevertheless the choice of themata is not dictated purely by such considerations but also by psychological, philosophical and aesthetic factors. Thus to understand the work of a scientist one should not only look at the rational and empirical aspects of his work, but more importantly the underlying psychological motivations that could be understood by studying his commitment to certain "themata". Although themata might not themselves be models, scientific models can nevertheless, and often quite directly, manifest characteristics of a themata. For example the atomic model as expressing the themata of "mechanism". The difference between model and themata lies in the level of abstraction and generality, with themata being more abstract and general than models. However, raising the unit of analysis from models to themata has the advantage of revealing the non-rational aspects of scientific enquiry, and the aesthetics and psychology of models which motivate the work of scientists.

Finally, I want to draw on Feyman's treatment of a similar set of issues pertaining to models. In his book *The Character of Physical Laws* Feynman (1967:50–52) discusses how the law of gravitation can be expressed in three different ways, namely as (i) action-at-a-distance, (ii) the field concept, (iii) minimum principle. From our point of view, through a natural extension of the usage of the term 'model', we can say that these three different expressions of the law of gravitation can be regarded as constituting three different models of the law of gravitation. However, according to him, although all three models of the law of gravitation are 'equivalent scientifically', he adds that

> ... psychologically they are very different in two ways. First philosophically you like them or do not like them ... Second, psychologically they are different because they are completely unequivalent when you are trying to guess new laws. (Feynman, 1967:53)

In other words, although they have the same 'reference', i.e. bodies under the influence of gravitational force, they each have different 'sense', 'meaning', or simply 'connotation'. Feynman further points out that the third model of the law of gravitation, i.e. the minimum principle model, is different from both the action-at-a-distance model and the field model because, as he sees it,

> ... we have lost the idea of causality, that the particle feels the pull and moves in accordance with it. Instead of that, it smells all the curves, all the possibilities, and decides which one to take (by choosing that for which the quantity is least). (Feynman, 1967: 52)

Feynman's reaction towards such cases is somewhat ambivalent; vacillating between accepting its (philosophical) significance and sometimes rejecting it in favour of the pragmatic criterion of choosing the mathematical formulation which gives the right answers to the empirical data.

5.1. Responses to models: scientific and philosophical levels

Now, what are the implications and significance of the discussion so far? Psychological, aesthetic and philosophical considerations can be seen as important and influential in determining the direction of scientific work. Which model or theory is adopted also has cultural implications and significance in influencing or shaping society's world-view. At the scientific level such a competition for one's preferred aesthetically, philosophically, or culturally-motivated scientific model can result in scientists working out different scientific theoretical proposals, so as to gain acceptance. At the philosophical level however, especially in cases where the (scientific) decision has been made and model M_x comes out as the clear victor, the conflict now assumes a different form, i.e. by shifting it from the scientific to the philosophical level. This is where the realism/anti-realism debate resurfaces.

Those who accept the ontology and the metaphysics of the victorious model would accept it in a realist sense. Those who do not, will attempt a non-realist interpretation of the model. However, there are those, especially philosophers, who would philosophically interpret scientific models in terms of either realism or non-realism. As Hooker (1985) has put it, non-realists, interpret science as giving not 'depth descriptions' but only 'surface descriptions'. For realists however, it is essential to insist on the claim that science is capable of giving us the truth about the nature of physical reality, i.e. of giving us 'depth descriptions'.

The controversy concerning realism and scientism takes on an important broader cultural significance in the face of what has generally been experienced as a loss of intuitive intelligibility of the physical world, or rather our description of it, due to quantum physics and relativity theory. The realist can claim that what she offers is a continuity in our understanding of the natural physical world; be it at the macroscopic or microscopic level. The language used to impart understanding of the ordinary macroscopic world equally provides understanding of microscopic phenomena. Our sense of causal explanation remains unchanged and hence we live (or at least: can pretend to live) in a familiar world even when crossing into the realm of the unobservable and microscopic. The challenge for the realist in relation to quantum phenomena is to return our sense of the familiar—or to re-interpret the theory in terms of structural realism.

The anti-realist on the other hand can claim that she need not return a sense of the familiar to us since the world has never been taken away from us in the first place. For the anti-realist, observable phenomena is all there 'really' is, and all forms of scientific representations—be it pictorial models or mathematical formalisms—are just symbolic representations of phenomena whose only requirement is empirical adequacy, as measured by its ability to capture or account for all relevant empirical facts/phenomena in its domain (Van Fraassen, 2004). This would be the anti-realist claim to a humanist interpretation of science. For the anti-realist, the realist's reification of theoretical entities and underlying causal processes amounts to scientism and scientific hegemony, for it is this move that takes away the world as we know it and duplicates a parallel reified conceptual world creating the sort of confusion found in Eddington's two chairs: the solid chair of ordinary everyday experience and the (counter-intuitive) physicist's chair made up of atoms separated by large volumes of empty space.

6. The cultural significance of the discourse on models and scientific realism

I want to add to my discussion of the cultural significance of the discourse on models and scientific realism by drawing on an exchange between Clifford Hooker and Bas Van Fraassen (see Churchland & Hooker, 1985), in a collection of essays by realist philosophers of science in response to Van Fraassen's (1980) , *The Scientific Image*, with a reply by Van Fraassen. Despite the technicalities of the arguments presented for and against scientific realism in the book, Clifford Hooker, in his article entitled 'Surface Dazzle, Ghostly Depths: An Exposition and Critical Evaluation of van Fraassen's Vindication of Empiricism against Realism', takes a surprising turn towards the end of his essay by putting the issue in a wider perspective:

> The basic divergences between realism and constructive empiricism have been delineated, but this does not exhaust the potential areas of mutual opposition. A last area of disputes remains, the relations between philosophy of science and the larger role of science in the human evolutionary process of the planet, i.e. disputes concerning the social, political, and cultural place and significance of science. (Hooker, 1985: 17)

Here Hooker clearly regards the discourse on scientific realism, and the different positions taken by realists and empiricists, as having a cultural significance. Hence, adopting a realist or antirealist position on models and scientific realism would mean steering science in different cultural directions. For Hooker, the empiricist or 'positivist' position (i.e. antirealist) such as van Fraassen's, would imply the abandonment of science to a utilitarian, technocratic, and inhumane culture devoid of humanistic values. Hooker (1985: 190) thinks that the antirealist 'serves only to obscure both the process [of scientific transformation] and what is at stake for humanity in it, and retains the view that science is at bottom value-neutral and separate from social processes as such, and emphasizes fact and logic as the sole cognitive determinants of science'. This view of science, according to Hooker, produces two distorting effects, one of which is that it '*leaves no distinctively ethical-spiritual, social, or rational structure to extra-scientific life, after all the major substance of life*' (Hooker, 1985: 191) (emphasis mine). This impression of the empiricist version of antirealism may be due to the empiricist's insistence that observable reality is all there is in science's attempt to provide knowledge of the natural world.

In his reply to Hooker, Bas van Fraassen (1984: 300-301) retorts that:

> . . . But to my surprise, we find in section 7 a telling attack on the *scientism* usually characteristic of such metaphysical positions today. Not only that, scientism seems to be laid at the door of empiricism. It seems to me to be exactly the realist who "*leaves no distinctively ethical-spiritual, social, or rational structure to extra-scientific life, after all the major substance of life*"[. . .] (emphasis mine). Empiricism does not pretend to supply such structure as Hooker seeks, to be sure, but leaves room for it. And it also leaves room for the freedom to be found in a life *without* a world picture.

The dispute between Hooker and van Fraassen epitomizes the different cultural implications of realism and antirealism. Only that in this case, each claim the other to be the culprit. To Hooker, Frassen's empiricism/antirealism implies the rejection of anything outside of logic and observation, and hence leaves no scope for the 'ethical-spiritual' in human life. Van Fraassen on the other hand, saw things in reverse and insisted that it is the realist, who by allowing science to penetrate all knowledge, leaves no room for the extra-scientific, including the realm of the 'ethical-spiritual'. Who in this case, is the real culprit, and truly scientistic—the realist or antirealist?

To help answer this question, it is instructive to turn to the view of another philosopher, Richard Rorty, who had also framed the issue of realism in a broader cultural context. In an article entitled "A Pragmatist View of Contemporary Analytic Philosophy", Richard Rorty (2007: 134) quoting Arthur Fine's article on "The Natural Ontological Attitude", where an analogy between realism and theism was made, approvingly reproduced Fine's words thus:

> In support of realism there seem to be only those 'reasons of the heart' which, as Pascal says, reason does not know. Indeed, I

> have long felt that belief in realism involves a profound leap of faith, not at all dissimilar from the faith that animates deep religious convictions[…]. The dialogue will proceed more fruitfully, I think, when the realists finally stop pretending to a rational support for their faith, which they do not have. Then we can all enjoy their intricate and sometimes beautiful philosophical constructions (of, e.g., knowledge, or reference, etc.) even though to us, the nonbelievers, they may seem only wonder-full castles in the air. (Fine, 1986: 116n.)

In an article "Pragmatism as anti-authoritarianism", Rorty (2007: 134) further expanded on Fine's analogy and suggested that 'we see heartfelt devotion to realism as the Enlightenment's version of the religious urge to bow down before a non-human power'. In his characteristically pragmatist view:

> The term "Reality as it is in itself, apart from human needs and interests" is, in my view, just another of the obsequious Names of God. In that article, I suggested that we treat the idea that physics gets you closer to reality than morals as an updated version of the priests' claim to be in closer touch with God than the laity. (Rorty, 2007: 134)

Here Rorty explicitly makes the connection between realism, the Enlightenment, and theology. In trying to explicate the relationship, he drew analogies between realism and theism, between physicists and priests. But instead of contrasting science with religion, Rorty aligned realism with science and the Enlightenment which he wanted to unmask as a new 'theism', of which he contrasts his own pragmatism or humanism. Interestingly, representationalism, too, is seen to be part of the equation:

> Representationalists are necessarily realists, and conversely. For realists believe both that there is one, and only one, Way the World Is In Itself, and that there are "hard" areas of culture in which this Way is revealed. In these areas, they say, there are "facts of the matter" to be discovered, though in softer areas there are not. By contrast, anti-representationalists believe that scientific, like moral, progress is a matter of finding ever more effective ways to enrich human life. They make no distinction between hard and soft areas of culture. (Rorty, 2007: 133)

Rorty's alignment of representationalism with realism has an interesting connection to the issue of models in science as discussed earlier. Those who take scientific models in the realist sense, are necessarily representationalists, and they regard science as giving us true knowledge about the world. Knuuttila (2005), in a recent article on models, presents a non-representationalist view of models, viewing it in a pragmatist spirit akin to Rorty's, thus confirming the same kind of distinction made by Rorty with regard to representation and realism.

In case one suspects Rorty of creating strawmen in order to build his own cultural view of pragmatism, let us look at the writings of Ernest Gellner on the question of scientific realism, modernity and the philosophy of science. Gellner was perhaps the philosopher of modernity par excellence, and to him 'science is the mode of cognition of industrial societies'. He believed that one must take the content of scientific theories seriously, not only as science but also as that which should constrain our world-view. In other words, our picture of the world should not only be informed by science, but we should be scientific realists if we are to cope with the modern world. To this effect Gellner wrote:

> This contention is often combined with another, to the effect that it is fundamentally mistaken to see science as a picture of the world we live in and of ourselves, to attribute to its abstractions and conceptual devices and hypotheses any ontological validity. This additional contention also seems to me wholly false. One cannot conjure away, dispose of the content of science, in this facile way. As an example of this kind of view, consider Professor J. M. Cameron's contention...that extracting pictures of the world from scientific theories 'has nothing to do with serious work in the sciences or in philosophy. (Gellner, 1964: 207)

The apparent tension existing in our taking the content of science seriously, and the denial that our morals or world-view be derived from them, is resolved by Gellner by insisting that 'our moral and orientational thought must be in terms of the world as we know it to be on the best evidence we happen to have available' (Gellner, 1964: 207).

Gellner's self-image as a 'modernist' philosopher of science is well-known, especially in his debates with Paul Feyerabend; retrospectively, Gellner described himself as an 'Enlightenment Rationalist' (Gellner, 1992). And in the passage quoted above, he insists that we should be scientific realists because our 'orientational thought' should be based on knowledge based on the best evidence that we have concerning the world, i.e. science.

As in the exchange between Hooker and van Fraassen above, there remains the question of what exactly are the philosophical and cultural implications of adopting a realist or antirealist position on models and science. The realist seeks to reassert the traditional role of science as natural philosophy, as episteme which gives us true knowledge about the world, hence privileging science's epistemological role in modern culture. The antirealist on the other hand wishes to deflect what they see as a scientistic intrusion into one's world-view in a world where the humanistic and religious sphere has shrunk in relation to the pervasive influence of science. For the realist, in turn, the antirealist position leaves a void in one's epistemic-cultural space, a void that needs to be filled in by a belief in science and the world-picture afforded by science. The problem of intelligibility of the world brought about by the breakdown of ordinary language in modern physics (Schrödinger, 1996) however, creates problems for the realist even if his epistemological and cultural goal is accepted. The current trend in the philosophy of science it seems, is to turn to structural realism as a means of saving the goal (see Ladyman, 1998; Zahar, 2007). Do we, or do we not need 'pictures of the world' in order to make sense of our existence in the contemporary modern world? For the antirealist, it seems that we do not, least of all from science. For the realist however, our modern condition requires it, for then we would 'feel at home' in a modern world built around science.

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