MEETING THE UNIVERSE HALFWAY: REALISM AND SOCIAL CONSTRUCTIVISM WITHOUT CONTRADICTION

Because truths we don't suspect have a hard time
making themselves felt, as when thirteen species
of whiptail lizards composed entirely of females
stay undiscovered due to bias
against such things existing,
we have to meet the universe halfway.
Nothing will unfold for us unless we move toward what
looks to us like nothing: faith is a cascade.
The sky's high solid is anything
but, the sun going under hasn't
budged, and if death divests the self
it's the sole event in nature
that's exactly what it seems.
[From the poem "Cascade Experiment", by Alice Fulton (Fulton, 1990)]

1. INTRODUCTION

The morning after giving an invited lecture on the socially constructed nature of scientific knowledge, I had the privilege of watching as a STM (scanning tunneling microscope) operator zoomed in on a sample of graphite, and as we approached a scale of thousands of nanometers ... hundreds of nanometers ... tens of nanometers ... down to fractions of a nanometer, individual carbon atoms were imaged before our very eyes. The experience was so sublime that it sent chills through my body – and I stood there, a theoretical physicist who, like most of my kind, rarely ventures into the basements of physics buildings experimental colleagues call "home", conscious that this was one of those life moments when the amorphous jumble of history seems to crystallize in a single instant. How many times had I recounted for my students the evidence for the existence of atoms? And there they were – just the right size and grouped in a hexagonal structure with the interatomic spacings as predicted by theory! "If only Einstein, Rutherford, Bohr, and especially Mach, could have seen this!" I found myself exclaiming. And as the undergraduate students operating the instrument (that they had just gotten to work the day before by carefully eliminating sources of vibrational interference – we're talking nanometers here!), disassembled the chamber which held the sample so that I could see for myself the delicate positioning of the probe above the graphite surface, expertly

L. H. Nelson and J. Nelson (eds), Feminism, Science, and the Philosophy of Science, 161–194.

cleaved with a piece of scotch tape, I mused outloud that "seeing" atoms will quickly become routine for students (as previous generations in turn found the examination of cells by visual light microscopes to be and then the structure of molecules by electron microscopes so) and that I was grateful to have been brought up in a scientific era without this particular expectation.

At this point in my story, I imagine there will be scientific colleagues who will wonder whether this presented a moment of intellectual embarrassment for your narrator who had on the previous night insisted on the socially constructed nature of scientific knowledge. In fact, although I was profoundly moved by the event I had just witnessed, standing there before the altar of the efficacy of the scientific enterprise, I was unrepentant. For as social constructivists have tried to make clear, empirical adequacy is not an argument that can be used to silence charges of constructivism. The fact that scientific knowledge is socially constructed does not imply that science doesn't "work", and the fact that science "works" does not mean that we have discovered human-independent facts about nature. (Of course, the fact that empirical adequacy is not proof of realism is not the endpoint, but the starting point for constructivists, who must explain how it is that our constructions work – an obligation that seems all the more urgent in the face of increasingly compelling evidence that the social practice of science is conceptually, methodologically, and epistemologically allied along particular axes of power.[1])

On the other hand, I stand in sympathy with my scientific colleagues who want science studies scholars to remember that there are cultural *and* natural/material causes for knowledge claims. While most social constructivists go out of their way to attempt to dispel the fears that they are either denying the existence of a human-independent world or the importance of material factors in the construction of scientific knowledge, the bulk of the attention has been on cultural factors. To be fair, this is where the burden of proof has been placed: social constructivists have been responding to the challenge to demonstrate the falsity of the worldview that takes science as the mirror of nature. Nonetheless, as both the range and sophistication of constructivist arguments have grown, the charge that they embrace an equally extreme position – that science mirrors culture – has been levied against them with increasing vigor. While few constructivists actually take such an extreme position, we would be remiss in simply dismissing this charge as a trivial oversimplification and misunderstanding of the varied and complex positions that come under the rubric of constructivism. For the anxiety being expressed, though admittedly displaced, touches upon the legitimate concern about the privileging of epistemological issues over ontological ones in the constructivist literature. Ontological issues have not been totally ignored, but they have been overshadowed.

The ontology of the world is a matter of discovery for the traditional realist. The assumed one-to-one correspondence between scientific theories and reality is used to bolster the further assumption that scientific entities are unmarked by the discoverers: that is, nature is taken to be transparently given. Acknowledging the importance of Cartwright's (1983) philosophical analysis decoupling these assumptions and her subsequent separation of scientific realism into two independent

positions – realism about theories and realism about entities – Hacking (1982), like Cartwright, advocates realism towards entities. Shifting the traditional emphasis in science studies away from theory construction to the examination of experimental practice, Hacking grounds his position on the ability of the experimenter to manipulate entities in the laboratory. Galison (1987) also centers experimental practice in his constructivist analysis comparing three different periods of twentieth-century physics experimentation, wherein he generalizes Hacking's criterion for the reality of entities by underlying the importance of the notions of stability (i.e., invariances of results under changing experimental conditions, rather than the narrower category of manipulation) and directness (i.e., epistemologically, but not necessarily logically, non-inferential). There are other constructivist approaches which go further in interrogating the transparency of our representations of nature. Latour (1993) prioritizes stability as well, posing it as one variable of a two-dimensional geometry whose other axis connects the poles of Nature and Society. Essence then becomes the trajectory of stabilization within this geometry that is meant to characterize the variable ontologies of quasi-objects. In contrast, Haraway (1988) emphasizes instability: it is the instability of boundaries defining objects that is the focal point of her explicit challenge not only to conceptions of nature that claim to be outside of culture, but also to the separation of epistemology from ontology. Interestingly, the instability of boundaries and Haraway's insistence that the objects of knowledge are agents in the production of knowledge, feature her notions of cyborgs (1985) and material-semiotic actors (1988) which strike up dissonant and harmonic resonances with Latour's hybrids and quasi-objects (1993). Moving to what some consider the opposite pole of the traditional realist position is the poststructuralist position. To many scientists as well as science studies scholars, Derridian forms of poststructuralism that disconnect sign from signified seem to be the ultimate in linguistic narcissism. While insisting that we are always already in the "theater of representation", Hayles (1993) takes exception to extreme views that hold that language is groundless play, and while she does not provide us with access to the real she does attempt to place language in touch with reality by reconceptualizing referentiality. Hayles' theory of constrained constructivism (1993) relies on consistency (in opposition to the realist notion of congruence) and the semiotic notion of negativity to acknowledge the importance of constraints offered by a reality that cannot be seen in its positivity: as she puts it, "Although there may be no outside that we can know, *there is a boundary*" (p. 40, original emphasis).

These attempts to say something about the ontology of our world are exceptions rather than the rule in the constructivist literature. There is a need to elaborate further upon the crafting of ontologies. We need to understand the technologies by which nature and culture interact. Does nature provide some template that gets filled in by culture in ways that are compatible with local discourses? Or do specific discourses provide the lenses through which we view the layering of culture upon nature? Does the full "texture" of nature get through or is it partially obliterated or distorted in the process? Is reality an amorphous blob that is structured by human discourses and interactions? Or does it have some complicated irregular shape that

is differently sampled by varying frameworks that happen to "fit" in local regions like coincident segments of interlocking puzzle pieces? Or is the geometry fractal so that it is impossible for theories to match reality even locally? At what level of detail can any such question be answered, if at all? And what would it mean? Is it possible to take any of these questions seriously within the academy, in the U.S., in the late twentieth century? Won't this still sound too much like metaphysics to those trained during the various states of decay of positivist culture? And if we don't ask these questions what will be the consequences? For as Donna Haraway reminds us, "what counts as an object is precisely what world history turns out to be about" (1988, 588). I seek some way of trying to understand the nature of the interplay of the material and the cultural in the crafting of an ontology. Consequently, I will place considerably more emphasis on ontological issues than is common in science studies, although I will not ignore the epistemological issues either, since like Haraway's material-semiotic actors, the ontology that I will offer is not outside of epistemology.

Upon articulating a new ontological and epistemological framework, I will own up to its realist tenor. After a resurgence of interest in scientific realism in the 1980s, its popularity seems to have waned once again, if not the result of the deathknell sounded by Fine's (1984) clever according of the metatheoretical failure of arguments for realism, then at least by the commonplace tendency on the part of constructivists to present scientific realism as naive, unreflexive, and politically invested in its pretense to assume an apolitical posture. In fact, the pairing of social constructivism with some form of antirealism has come to seem almost axiomatic: if we acknowledge the cultural specificity of scientific knowledge construction, are we not obligated to relinquish the hope of constructing theories that are true representations of independent reality? For example, in offering a concrete case of the underdetermination thesis, Cushing (1994) argues that the fact that distinctive theories can account for the same empirical evidence means that realists are hard-pressed to make an argument for theoretical access to the actual ontology of our world.[2] For the most part, social constructivists have expressed either outright disdain for or at least suspicion towards realism, and have explicitly adopted antirealist positions, or they have refused the realism–antirealism debate altogether either because they feel limited by this very opposition (see for example Fine, 1984; Pickering, 1994) or they have thought it more fruitful to focus on other issues. As an admitted social constructivist, I must confess to having sympathy with all of these positions, but I do not want to deny my own realist tendencies or the realist features of the framework I present. While I acknowledge that realism has been invoked to support both oppressive and liberatory positions and projects, my hope is that at this historical juncture, the weight of realism – the serious business and related responsibility involved in truth hunting – can offer a possible ballast against the persistent positivist scientific culture that too easily confuses theory with play (see Barad, forthcoming).

Realizing the multiplicity of meanings that realism connotes, at this juncture I want to clarify how I take realism in the first instance. As a starting point, I follow Cushing's lead:

I assume, perhaps unreasonably, that a scientific realist believes successful scientific theories to be capable of providing reliable and understandable access to the ontology of the world. If one weakens this demand too much, not much remains, except a belief in the existence of an objective reality to which we have little access and whose representation by our theories is nebulous beyond meaningful comprehension. In such a situation, is it worth worrying about whether or not one is a realist? (Cushing, 1994, 270, fn. 26).

Although I will ultimately add substantive qualifications to this definition, I do not intend to weaken what I take to be the spirit of this demand, and I therefore have selected this starting point to clarify the sense of realism with which I mean to engage, as separate from some other more general uses in the science studies literature, including discussions that oppose realism to relativism, or realism to linguistic monism, or realism to subjectivism. My first concern is not with realism in these senses: I grant that there are forms of antirealism that are not relativist, that do not deny the existence of an extralinguistic reality, and that are compatible with various notions of objectivity. That is, in the spirit of Cushing's query, I want to limit the elasticity of the meaning of realism for my initial purposes. Science studies scholars have labored long and hard to articulate moderate social constructivist positions that reject the extremes of objectivist, subjectivist, absolutist, and relativist stances, but it is perhaps inappropriate to label these as realist on just such bases alone. That is, I do not want to turn these accomplishments aside by setting up realism as the foil to the entire family of apparitions, including some that scientists find most haunting. For example, feminist science studies scholars in particular have overwhelmingly rejected the specter of epistemological relativism, with an intensity shared by scientists (a fact which may come as a surprise to scientists who have not studied the feminist literature). Seeing epistemological relativism as the mirror twin of objectivism, and both as attempts to deny the embodiment of knowledge claims, feminist theories of science including Haraway's theory of situated knowledges (1988), Harding's strong objectivity (1991), Keller's dynamic objectivity (1985), and Longino's contextual empiricism (1990) articulate nonrelativist constructivist positions. Consequently, although my discussion of realism in this paper is concerned with the sense in which access to the ontology of our world is possible, additionally I will also attempt to satisfy the high standards that have already been set by specifying the ways in which the new form of realism that I propose rejects these other extreme oppositions. I use the same label, "agential realism", for both the new form of realism and the larger epistemological and ontological framework that I propose. (My motivation for using an adjectival form of agency as the modifier will be clarified later.)

2. AGENTIAL REALISM: AN OVERVIEW

The inspiration for agential realism comes from my reading of Niels Bohr's philosophy-physics. (I use this hyphenated structure, instead of the usual "philosophy of physics", to emphasize Bohr's unwillingness to think of these interests as distinctive in any sense, contrary to the sharp disciplinary boundaries that are

important to contemporary physics culture (Barad, 1995).) Bohr's philosophy-physics provides a fruitful starting point because it involves a critical examination of observation/measurement processes: in contrast to the inconsequential role of the observer in Newtonian physics, Bohr argued that quantum physics requires a new logical framework that takes the observation processes into account. Measurement is a potent moment in the construction of scientific knowledge – it is an instance where matter and meaning meet in a very literal sense. For example, in the context of studies of the practice of experimental high-energy physics, science studies scholars have emphasized the role of detectors as sites for making meaning (Traweek, 1988; Galison, 1987; Pickering, 1984). My focus here is on the embodiment of culture within *theory*. That is, I read Bohr's philosophy-physics as an argument for the necessity of including practice within theory: that, contrary to traditional views of physical theory that take the actual practice of measurement to be outside of theory, and according to the logical positivist/empiricist program which assumes that measurements transparently adjudicate among theories, Bohr situates practice within theory, since to ignore practice is to get the theory wrong. This is not to suggest that all is reduced to theory, but that theory, as a matter of principle, must itself be embodied in practice and cannot abstract itself from these issues.[3] While I fully suspect postmodern readers to be readily suspicious of theoretical moves that elevate practical issues to the realm of principles, I will show that this implicit universality amounts to the common constructivist assertion that all knowledges are local knowledges. That is, I will indicate how this theoretical analysis of measurement can be understood as the literal embodiment of objectivity in the sense of Haraway's theory of situated knowledges (1988; see also Barad, 1996).

Now I am quite aware that the ubiquitous appropriation of quantum theory makes it dangerous material to handle these days, and the addition of feminist theory to my list of concerns seems to be quite enough to detonate the explosive mixture, so a few preliminary words of caution are in order. In a sense, to accomplish my task I need to "rescue" quantum theory from both its overzealous advocates and its unreflective practitioners. In the popular literature quantum physics is often positioned as the scientific path leading out of the West to the metaphysical garden of Eastern mysticism. Paralleling these popular renditions, one can find suggestions in the feminist literature that quantum physics is inherently less androcentric, more feminine, and generally less regressive than the masculinist tendencies found in Newtonian physics. But those who naively embrace quantum physics as some exotic Other that will save our weary Western souls forget too quickly that quantum physics underlies the workings of the A-bomb, that particle physics (which relies on quantum theory) is the ultimate manifestation of the tendency towards scientific reductionism, and that quantum theory in all its applications continues to be the purview of a small group of primarily Western-trained males. It is not my intention to contribute to the romanticizing or mysticizing of quantum theory. On the contrary, as a physicist, I am interested in engaging in a rigorous dialogue about particular aspects of specific discourses on quantum physics and the implications. Similarly, I do not make any claims here about Niels

Bohr being an unappreciated or closet feminist. Nor is my aim to critique physics by holding it up to some fixed notion of gender. On the contrary, the feminist analysis I present here simultaneously interrogates the notions of identity and science.[4]

On the other hand, I part company with my neo-positivist physics colleagues who believe that philosophical concerns are superfluous to the real subject matter of physics. Indeed, I am sympathetic to Bohr's view that philosophy is integral to physics. Niels Bohr was one of the most important physicists of the twentieth century, and his "philosophical" writings span a period of approximately four decades.[5] Bohr is considered to be the primary author of the so-called Copenhagen interpretation of quantum mechanics.[6] Although alternative interpretations have been advanced ever since the formulation of quantum theory during the mid-1920s, the physics community claims allegiance to the Copenhagen interpretation.[7] Unfortunately, the vast majority of physicists have no more than a passing interest in the philosophical issues, and prefer to focus on the powerful tools that the quantum formulation provides for purposes of calculation. This avoidance has had its cost: the foundational issues of this fundamental physical theory remain unresolved and the culture of physics is such that unreflective attitudes and approaches are rewarded. While I will not make any arguments about the superiority of Bohr's approach to quantum physics, the simultaneous centrality and marginality of his approach makes it particularly interesting.[8]

Bohr often makes reference to the epistemological lessons of quantum theory, and he sees the framework that he offers for quantum physics as having general relevance beyond physics (Folse, 1985). So it is not at all inappropriate that attention has been given to the larger philosophical implications of Bohr's philosophy-physics, leaving specific issues surrounding the interpretation of quantum theory aside. My approach will be to draw out the specifics of a consistent Bohrian framework, grounding the analysis in the physics, and then to consider the larger implications.

The first task is necessary since there is much disagreement in the secondary literature about how to interpret Bohr. For example, Bohr has been called a positivist, an idealist, an instrumentalist, a (macro)phenomenalist, an operationalist, a pragmatist, a (neo)Kantian, and a realist by various authors. One of the difficulties in assigning a traditional label to Bohr's interpretative framework is the fact that Bohr is not specific about his ontological commitments. In order to fill this crucial gap, I propose an ontology that I believe to be consistent with Bohr's views, although I make no claim that this is what he necessarily had in mind. That is, as a result of Bohr's inattentiveness to concerns of ontology, there will be vast differences in opinion about this matter, and I am less interested in trying to figure out what Bohr was actually thinking than what makes sense in the context of what Bohr does tell us. My approach is to use Bohr's writings as the context for my thinking about these issues; I do not take them as scripture (see Methodological Interlude). Using this analysis of Bohr's philosophy-physics as inspiration, I introduce agential realism as a framework that ties together the epistemological and ontological issues.

I then show how agential realism can be used to address particular concerns that social constructivist approaches to science make apparent, including some of the ones enumerated in the previous section. I diverge from Bohr in strategy here, but not in spirit. Bohr's methodological approach was to draw out the epistemological lessons of quantum theory for other fields of knowledge by essentially trying to guess what the relevant Complementary variables would be in each arena. This analogic strategy often failed: both because he proposed a set of variables that turned out not to be Complementary, and because the implications drawn on this basis watered down the complexity and richness of the "epistemological lessons".[9] My approach will be to examine specific implications by directly taking on a different set of epistemological and ontological commitments. That is, I will not use the notion of Complementarity as a springboard; instead I directly interrogate particular philosophical background assumptions that underlie specific concerns.

Finally, I want to make explicit the distinction between my approach and a host of analogical (mis)appropriations of quantum theory that are more common in the literature than physicists would wish. I will not put forward any argument to the effect that quantum theory of the microworld is analogous to situations that interest us in the macroworld – be they religious, spiritual, psychological, or even those encountered in science studies. My focus is on the development of widely applicable epistemological and ontological issues, that can be usefully investigated by a rigorous examination of measurement processes as explicated by Bohr's understanding of quantum physics. To ask whether it is not suspect to apply arguments made specifically for microscopic entities to the macroscopic world is, in this case, to mistake the approach as analogical. The epistemological and ontological issues are not circumscribed by the size of Planck's constant (see note 12). That is, I am not interested in mere analogies but rather widely applicable philosophical issues such as the conditions for objectivity, the appropriate referent for empirical attributes, the role of natural as well as cultural factors in scientific knowledge production, and the efficacy of science.

3. MEASUREMENT MATTERS

> Often the development of physics has taught us that a consistent application of even the most elementary concepts indispensable for the description of daily experience, is based on assumptions initially unnoticed, the explicit consideration of which is, however, essential if we wish to obtain a classification of more extended domains of experience as clear and as free from arbitrariness as possible .... This development has contributed to the general philosophical clarification of the principles underlying human knowledge (Bohr, 1937, 289–290).

Classical epistemological and ontological assumptions, such as the ones found to underlie Newtonian physics, include an autonomously existing world that is describable independently of our experimental investigations of it. This accounts for the fact that the process of measurement is transparent and external to the discourse of Newtonian science. It is assumed that objects and observers occupy physically and conceptually separable positions. Objects are assumed to possess well-defined intrinsic attributes, and it is the job of the scientist to cleverly discern these inherent

characteristics, obtaining the values of the corresponding context-independent variables through some benignly invasive measurement procedure. The reproducibility of measured values under the methodology of controlled experimentation is used in support of the objectivist claim that what has been obtained is an objective representation of intrinsic properties that characterize the objects of an uncontrolled, independent reality.[10] The transparency of the measurement process in Newtonian physics is a root cause of its value to and prestige within the Enlightenment culture of objectivism.

The two basic assumptions of measurement transparency underlying Newtonian physics that were challenged by Bohr's interpretation of quantum physics are:[11]

(1) Measurements involve continuous, determinable interactions; that is, an unambiguous, inherent, Cartesian-like cut between knower and known delineates object from observational apparatus.

(2) The applicability of conceptual schema is independent of measurement processes; concepts are abstractable, universal, definite, and context-independent.

The hallmark of Newtonian physics is its determinism, its proclaimed ability to predict and retrodict the full set of physical states of a system for all time: given the initial conditions (i.e., the simultaneous specification of position and momentum at one instant in time), entire particle trajectories can be calculated. In the Newtonian picture, the position and momentum of an object can be determined by a time-of-flight measurement, for example, in which light impinges on the object and the scattered light is collected at a detector. Although light has momentum and energy, the process of illuminating the object can either be made to impart negligible disturbance on the object (intuitively, by continuously lowering the intensity) or the disturbance can be determined and subtracted out, thereby yielding the desired values of the position and the momentum of the object as they would have been had the measurement not been performed. According to Niels Bohr, this objectivist account of the measurement process rests on false assumptions.[12]

Quantum physics is based on an empirically verified discreteness or discontinuity (the quantum of action = Planck's constant = $h \neq 0$) in measurement interactions, initially observed in experiments probing atomic phenomena at the turn of the century. The lack of continuity means that measurement interactions cannot be reduced to the point of being negligible and, therefore, determination of the properties of an independent object are contingent upon subtraction of the effects of the measurement interaction. Bohr argued that subtraction is impossible; that the measurement interaction cannot be precisely specified without intervening in such a way as to disrupt the purpose of the intended measurement. Furthermore, he argued that *the indeterminable discontinuity undermines the separability of the "object" and the "agencies of observation"*.

Bohr's argument for the indeterminability of measurement interactions is based on his insistence that *concepts are defined by the circumstances required for their measurement*, and therefore mutually exclusive experimental arrangements would need to be employed simultaneously (which is impossible) in order to determine all

the features of the measurement interaction. For example, in a time-of-flight measurement used to determine the initial conditions, the momentum imparted by the light impinging on the object would need to be subtracted out. But a measurement of the momentum requires an apparatus with movable parts (i.e., the concept 'momentum' is necessarily defined by reference to an apparatus with movable parts[13]), which would then exclude the equally necessary measurement of the position since position measurements require an apparatus with fixed parts (i.e., the concept 'position' is necessarily defined by reference to a fixed apparatus). Therefore, observation is only possible on the condition that the interaction is indeterminable (i.e., it cannot be subtracted out). Consequently, since observations involve an indeterminable discontinuous interaction, *as a matter of principle, there is no unambiguous way to differentiate between the "object" and the "agencies of observation" – no inherent/naturally occurring/fixed/universal/Cartesian cut exists.* Hence, *observations do not refer to objects of an independent reality.* Bohr's interpretation of quantum theory provides profound challenges to both of the assumptions of measurement transparency underlying the Newtonian framework. In fact, Bohr's philosophy-physics undermines a host of Enlightenment notions, requiring him to construct a new logical framework (see especially, Folse, 1985), including a new epistemology, for understanding science.

Bohr moves away from reference to the classical notion of 'disturbance' in his later writings and emphasizes "*quantum wholeness*", or *the lack of an inherent/Cartesian distinction between the "object" and the "agencies of observation*", as the central feature of his new descriptive framework. For Bohr, "*object" and "agencies of observation" form a nondualistic whole in the sense that it is conceptually incoherent to refer to an inherent distinction between the two. "Descriptively*, there is a *single* situation, no part of which can be abstracted out without running into conflict with other such descriptions (namely, those of complementary situation). The object cannot be ascribed an 'independent reality in the ordinary physical sense'" (original italics; Hooker, 1972, 156). This is a central notion in Bohr's philosophy-physics and he uses the term "*phenomenon*" (in his later writings) *to designate particular instances of wholeness*: "While, within the scope of classical physics, the interaction between object and apparatus can be neglected or, if necessary, compensated for, in quantum physics this *interaction thus forms an inseparable part of the phenomenon.* Accordingly, *the unambiguous account of proper quantum phenomena must, in principle, include a description of all relevant features of the experimental arrangement*" (my italics, Bohr, 1963c, 4). Furthermore, "[t]he essential wholeness of a proper quantum phenomenon finds logical expression in the circumstance that any attempt at its well-defined subdivision would require a change in the experimental arrangement incompatible with the appearance of the phenomenon itself" (Bohr 1963b, 72).

If a cut delineating the "object" from the "agencies of observation" is not inherent, what sense, if any, should we attribute to the notion of observation? Bohr suggests that "by an experiment we simply understand an event about which we are able in an unambiguous way to state the conditions necessary for the reproduction

of the phenomena" (quoted in Folse, 1985, 124). The specification of these conditions is tantamount to *the introduction of a constructed/agentially positioned/movable/local/"Bohrian" distinction between an "object" and the "agencies of observation"*.[14] That is, although no inherent distinction exists, every measurement involves a particular choice of apparatus, providing the conditions necessary to give definition to a particular set of classical variables, at the exclusion of other essential variables, and thereby placing a particular constructed cut delineating the "object" from the "agencies of observation". *This particular constructed cut resolves the ambiguities only for a given context; it marks off and is part of a particular instance of wholeness, that is, a particular phenomenon.*

For example, consider once again an experiment in which light is scattered from a particle. The scattered light may be directed towards a photographic plate rigidly fixed in the laboratory and therefore used to record the position, or the light may be directed towards a piece of equipment with movable parts used to record the momentum of the scattered light. The first case essentially describes the process of taking a picture of a particle with a flash camera. In that case, the light is part of the measuring apparatus. In the latter case, the light's momentum is being measured and hence it is part of the object in question.[15] (This example nicely illustrates the Bohrian assertion that observation is possible only on the condition that the measurement interaction is indeterminable: since at least one particle of light, or photon, is required to make a mark on the film recording the position (illustrating the "quantum discontinuity"), and since the effect that this photon has on the particle cannot be accounted for unless the photon's momentum is simultaneously determined, and given that both variables ("position" is definable in the context of an apparatus with a fixed photographic plate, and "momentum" is definable in the context of photographic plate on a movable platform) cannot be unambiguously defined using one particular choice of measuring apparatus, the observation entails an indeterminable interaction.) Therefore, the measurement of unambiguously defined quantities is possible through the introduction of a constructed cut which serves to define "object" and "agencies of observation" *in a particular context*.[16]

Especially in his later writings, Bohr insisted that quantum mechanical measurements are "objective".[17] Since Bohr also emphasized the essential wholeness of phenomena, he cannot possibly have meant that measurements reveal objective properties of independent objects. Rather Bohr's use of the term "objectivity" is tied to the fact that "[n]o explicit reference is made to any individual observer" (Bohr, quoted in Murdoch, 1987, 99). "Objective" means reproducible and unambiguously communicable – in the sense that "permanent marks ... [are] left on bodies which define the experimental conditions":

> Common to the schools of so-called empirical and critical philosophy, an attitude therefore prevailed of a more or less vague distinction between objective knowledge and subjective belief. By the lesson regarding our position as observers of nature, which the development of physical science in the present century has given us, a new background has, however, been created just for the use of such words as objectivity and subjectivity. From a logical standpoint, we can by an objective description only understand

a communication of experience which does not admit of ambiguity as regards the perception of such communications (Bohr, quoted in Folse, 1985, 15).

Clearly, Bohr's notion of "objectivity", which is not predicated on an inherent/Cartesian distinction between "objects" and "agencies of observation", stands in stark contrast to any Newtonian sense of "objectivity" denoting observer independence.

Bohr's term "agencies of observation" is evocative of the central role of agency in the new epistemological and ontological framework that I will introduce later in this paper. "Agencies of observation", instead of the more common term "observer", already signals the inseparability of the material and semiotic apparatuses. That is, in my reading, a pivotal point in Bohr's analysis is that *the physical apparatus (existing in the realm of classical, macroscopic, everyday, direct experience) marks the conceptual subject–object distinction: the material and semiotic apparatuses form a non-dualistic whole*. In other words, classical descriptive concepts obtain their *meaning* by reference to a particular physical apparatus which in turn marks the placement of a constructed cut between the "object" and the "agencies of observation". Finally, the point of reference for unambiguous communication is "from permanent marks – such as a spot on a photographic plate, caused by the impact of an electron – left on the bodies which define the experimental conditions" (Bohr, 1963c, 3). Therefore, "bodies which define the experimental conditions" serve as both the endpoint and the starting point for meaningful observation. For Bohr, measurement and description entail one another (though not in a narrowly operationalist sense but in the sense of epistemological indistinguishability).

Quite atypical of the writings of theoretical physicists, Bohr's writings often include very detailed drawings of experimental apparatuses. As Honner points out "Bohr insisted on providing elaborate drawings of mechanical devices used for observing quantum events [in many of his discussions of complementarity], as if to emphasize the connection between descriptive concepts and classical apparatus" (Honner, 1987, 119). Though Bohr was a theoretical physicist, he was obsessed with the details of measurement and was not satisfied to deal with abstract concepts – for Bohr *meaning is tied to the experiential world*.[18] (There is historical evidence that Rutherford, whom some regard as the greatest experimental physicist of this century, had a profound influence on Bohr, who was a postdoc under Rutherford.)

The question remains: what is the referent for a given objective property (as unambiguously defined in reference to a given constructed cut) that is obtained by a given measurement process? Since there is no inherent distinction between object and instrument, the property which is determined cannot be meaningfully attributed to either an abstract object or an abstract measuring instrument. That is, the measured value is neither attributable to an observation-independent object, nor is it a property created by the act of measurement (which would belie any sensible meaning of the word "measurement").[19] My reading is that the *measured properties refer to phenomena*, remembering that the crucial identifying feature of phenomena is that they are particular instances of wholeness, that "the unambiguous account of proper quantum phenomena must, in principle, include a description of all relevant features of the experimental arrangement" (Bohr, 1963c, 4).

Implicit in our classical descriptive concepts is a subject–object distinction, and since phenomena entail the placement of a constructed subject–object distinction, it is consistent to use classical concepts to describe phenomena. In fact, Bohr strengthens the claim for the appropriateness of our use of classical concepts to describe phenomena to one of necessity. The following detailed mapping of the relationship between classical concepts and phenomena can be given to provide justification for this move: since by their very definition classical descriptive concepts entail a particular subject–object distinction, as specified by the circumstances required for their measurement, and since phenomena include a constructed subject–object distinction, namely the one in question that gives definition to a particular classical concept, it follows that these particular classical concepts are just the ones that are useful in describing phenomena.[20] That is, phenomena are necessarily described using concepts conditioned by particular subject–object distinctions. Another way to appreciate the necessity of this condition is that unambiguous communication necessarily refers to "permanent marks ... left on bodies", that is macroscopic bodies, that in a particular context are defined as the "apparatus", and since the "apparatus" in turn specifies the circumstances required for the definition of particular classical concepts (derived from everyday experience in the macroscopic world and therefore premised on an object–subject distinction), it follows that phenomena, which include the particular constructed cut in question, are necessarily described using classical concepts appropriate to the given context. Again, *reference must be made to bodies in order for concepts to have meaning*.

"While in the [classical] mechanical conception of nature, the subject-object distinction was fixed, room is provided for a wider description through the recognition that the consequent use of our concepts requires different placings of such a separation" (Bohr, 1963b, 92). In fact, according to Bohr's Principle of Complementarity all possible ways of drawing the subject–object distinction must be considered to obtain the maximal accounting of our investigations. That is, mutually exclusive constructed cuts constituting mutually exclusive experimental circumstances, thereby agentially manifesting mutually exclusive phenomena serve to denaturalize the nature of the observational process.

Bohr's epistemological and descriptive framework is radically different from that associated with Newtonian physics. For Bohr, measurement, far from being external to the discourse of scientific theories, must play a prominent role in scientific theorizing: that is, Bohr situates practice within theory. As a result, method, measurement, description, interpretation, epistemology, and ontology are not separable considerations. These connections are explored in the sections following the Methodological Interlude.

4. METHODOLOGICAL INTERLUDE

Einstein once remarked of Bohr, "He utters his opinions like one perpetually groping and never like one who believes to be in possession of definite truth" (Einstein, quoted in Pais, 1982, 417).

Many of the philosophers, historians, and the few physicists who have tried to read Bohr's works have commented on the difficulty of this task. Bohr's style is atypical of most science writing. His writing reflects a self-conscious regard of his own descriptive process, which is consistent with his thorough-going examination of the role of description in scientific knowledge production, fundamental to his approach to understanding quantum physics. In like manner, I have tried to remain attentive to my own descriptive/interpretative process in my reading of Bohr. Consequently, I make no claims here to have discovered what Bohr was actually thinking or intending, as separate from my own interpretative apparatus; rather I attempt to provide a consistent reading within the context of particular ways of resolving ambiguities. (Recall that for Bohr descriptions refer to phenomena, not to some independent reality.) There are clear parallels between this methodology and feminist and other located-knowledges methodologies. This is not mere coincidence but, as will become clear later, a reflection of a common critical reflexivity.

My presentation of the major features of Bohr's post-Newtonian framework and corresponding epistemology come from more than a decade of extensive study of Bohr's writings. Interpretative questions about quantum theory plagued me as a graduate student in theoretical particle physics. (It may seem peculiar to non-scientists to discover that physics graduate school is not the appropriate context for engaging such questions.[21]) By the time I was an assistant professor of physics, my focus broadened to include the larger philosophical issues in Bohr's post-Newtonian framework.

The ideas as I have presented them so far are in considerable agreement with individual features of many of the standard secondary texts on Bohr's philosophy of physics, including the work of Feyerabend (1962), Hooker (1972), Bohm (1985), Folse (1985), Petersen (1985), Honner (1987), and Murdoch (1987). It is important to point out that the views of these scholars are widely divergent on many crucial points. I do not agree *in toto* with the views presented in any of these other accounts, though as I read through the primary texts time and again from the perspective of a theoretical particle physicist, various aspects of these works have been and continue to be helpful to me while I formulate my own evolving views on Bohr's philosophy-physics.

As a measure of the disagreement among Bohr scholars, consider the question of the nature of Bohr's interpretative framework. Most Bohr scholars, and many other scholars who have not studied Bohr, attribute some form of antirealism to Bohr, who has been called a positivist, an idealist, an instrumentalist, a (macro)phenomenalist, a relativist, a pragmatist, and a (neo)Kantian. Folse has been one of the strongest proponents of the minority view that sees Bohr as a realist. As I indicated in the Introduction, one of the difficulties in resolving the ambiguities in Bohr's position is that Bohr focuses on epistemological issues in his writings and he never spells out his ontological commitments. Consequently, it is difficult to discern the nature of any correspondence he may hold between theory and reality. Without a clear-cut presentation of a coherent Bohrian ontology, the task of determining what kind of realist or antirealist position is consistent with Bohr's philosophy-physics seems

doomed. In the next section, I present an ontology I believe to be consistent with Bohr's views, and I then address the question of a correlative interpretative stance.

I will argue that Bohr's philosophy-physics can be understood to be consistent with a particular form of realism, that I label "agential realism". But at I noted from the outset, my aim is not so much to provide a faithful representation of Bohr's philosophy-physics, as to propose a framework for thinking about critical epistemological and ontological issues, particularly in science studies. In addressing these issues in the remainder of the paper it would be just as dishonest to attribute the full development of this framework to Bohr as it would be to deny that my thinking about Bohr's philosophy-physics is everywhere present in my formulation.

5. AGENTIAL REALITY AND AGENTIAL REALISM

> Bohr has often been badly misunderstood, I believe, because his readers have insisted on reading the classical ontological and epistemological assumptions into ... [his] remarks ... it presupposes some autonomously existing atomic world which is describable independently of our experimental investigation of it. There is no such world for Bohr.... There is no godlike approach possible to the physical world whereby we may know it as it is "absolutely in itself"; rather we are able to know only as much of it as can be captured in those situations which we can handle conceptually – that is, those situations where unambiguous communication of the results is possible. ... This is in complete contrast to the classical realist metaphysics and epistemology where the world is concerned as being the way classical theory says it is, independently of our experimental exploration of it. ... (Clifford A. Hooker, 1972, 155–6)

The realism–antirealism distinction is often drawn on the basis of questions about belief in a correspondence theory of truth, which is rooted in a subject–object / culture–nature / word–world dualisms. The separation of epistemology from ontology is a reverberation of these dualism. Bohr's philosophy clearly contests a Cartesian (inherent, fixed, universal) subject–object distinction, and I will argue here that this undermines conceptions which see reality as either prior to or outside of language. What is being described is our participation *within* nature.

Aage Petersen, in an article entitled "The Philosophy of Niels Bohr", writes:

> Traditional philosophy has accustomed us to regard language as something secondary, and reality as something primary. Bohr considered this attitude toward the relation between language and reality inappropriate. When one said to him that it cannot be language which is fundamental, but that it must be reality which, so to speak, lies beneath language, and of which language is a picture, he would reply "We are suspended in language in such a way that we cannot say what is up and what is down. The word 'reality' is also a word, a word which we must learn to use correctly"[22] (Petersen, 1985, 302).

In my effort to provide a consistent Bohrian meaning to the term 'reality', I turn to a very important passage from Bohr's writings: a passage from his response to the 1935 paper of Einstein, Podolsky, and Rosen, the so-called "EPR paper", wherein Bohr directly challenges the EPR definition of "physical reality".[23] Many scholars have pointed out that the argument Bohr articulates in this passage is pivotal to his attempt to discredit the analysis of EPR and to resolve the "EPR paradox" once and for all. I say this both to highlight the fact that I have not chosen some obscure or arbitrary passage from Bohr's writings, but the one in which Bohr has the most at stake in being careful with the presentation of his ideas on the notion of reality, and also to express my surprise that none of the scholarship that I have read on Bohr

emphasizes the *positive* feature of this passage – that Bohr offers his own definition of physical reality in the final sentence:

> From our point of view we now see that the wording of the above-mentioned criterion of physical reality proposed by Einstein, Podolsky, and Rosen contains an ambiguity as regards the meaning of the expression "without in any way disturbing the system". Of course there is in a case like that just considered no question of a mechanical disturbance of the system under investigation during the last critical stage of the measuring procedure. But even at this stage there is essentially the question of *an influence on the very conditions which define the possible types of predictions regarding the future behaviour of the system*. Since these conditions constitute an inherent element of the description of any phenomenon to which the term "physical reality" can be properly attached, we see that the argumentation of the mentioned authors does not justify their conclusion that quantum-mechanical description is essentially incomplete (original italics, Bohr, 1935, 700).

In discussing Bohr's use of the word 'phenomenon' earlier, I pointed out that the conditions which define the possible types of predictions constitute an inherent element of the description of any phenomenon. Therefore, the first phrase of the last sentence is consistent with Bohr's use of the term phenomenon.[24] The last sentence then indicated that the term 'physical reality' can properly be attached to the phenomenon. *Phenomena are constitutive of reality*. Reality is not composed of things-in-themselves or things-behind-phenomena, but things-in-phenomena.

This interpretation is consistent with the following point made by von Weizsäcker:

> The fact that classical physics breaks down on the quantum level means that we cannot describe atoms as "little things". This does not seem to be very far from Mach's view that we should not invent "things" behind the phenomena. But Bohr differs from Mach in maintaining that "phenomena" are always "phenomena involving things", because otherwise the phenomena would not admit of the objectification without which there can be no science of them. For Bohr, the true role of things is that they are not "behind" but "in phenomena" (quoted in Honner, 1987, 15).

Or as Honner puts it:

> The term [phenomenon] was not intended to signify the uninterpreted appearance of the object of experience itself. Nor was Bohr trying to follow the Kantian distinction between the thing-in-itself and our perception of it. If one wanted to talk about such "things", then they were as Weizsäcker put it, to be found *in* the phenomena rather than behind it (Honner, 1987, 68).

The nature of this relationship is a point of contention among Bohr scholars. My own studies of Bohr's writings brought me to a conclusion similar to von Weizsäcker's before I ever started reading any of the secondary texts, and in spite of subsequent readings of the many different interpretations offered, it has always seemed very clear to me that this is the only interpretation that respects the complex intention of the Bohrian notion of 'phenomena'.[25] The point is that phenomena constitute a non-dualistic whole so that it literally makes no sense to talk about independently existing things as somehow behind or as the causes of phenomena. A Bohrian ontology does not entail some fixed notion of being that is prior to signification (as the classical realist assumes), but neither is being completely inaccessible to language (as in transcendental idealism) nor completely of language (as in linguistic monism) – what is being described is our participation *within* nature, what I term "agential reality".

Bohr often refers to the fact that we are in nature: "In our own century the immense progress of the sciences has ... given us an unsuspected lesson about *our position as observers of that nature of which we are part ourselves*" (my emphasis, Bohr, 1963c, 8). The introduction to the collection *Essays 1933–1957 on Atomic Physics and Human Knowledge* begins:

> The importance of physical science for the development of general philosophical thinking rests not only on its contributions to our steadily increasing *knowledge of that nature of which we ourselves are part*, but also on the opportunities which time and again it has offered for examination and refinement of our conceptual tools (my emphasis, Bohr, 1963b, 1).

The passage from Bohr's response to EPR continues:

> On the contrary, this description, as appears from the preceding discussion, may be characterized as a rational utilization of all possibilities of unambiguous interpretation of measurements, compatible with the finite and uncontrollable interaction between objects and the measuring instruments in the field of quantum theory. In fact, it is only the mutual exclusion of any two experimental procedures, permitting the unambiguous definition of complementary physical quantities, which provides room for new physical laws, the co-existence of which might at first sight appear irreconcilable with the basic principles of science. It is just this entirely new situation as regards the description of physical phenomena that the notion of *complementarity* aims at characterizing (original italics).

Notice that in this last sentence we are told that scientific theories describe physical phenomena. Since phenomena constitute agential reality, and it is phenomena that scientific theories describe, it follows that scientific theories describe agential reality. Were it not for the crucial adjective "agential", emphasizing the non-objectivist nature of Bohrian ontology, as I've described it here, the conclusion of this syllogism would sound like the proclamation of a die-hard realist who is advocating a classical correspondence theory of truth. However, the correspondence in question is between theories and *agential reality*, not an observer-independent reality. Hence, I conclude that Bohr's framework is consistent with a particular notion of realism, which I label "agential realism". Agential realism is compatible with the point I made earlier in this section that any notion of realism that is consistent with Bohr's philosophy must not be parasitic on subject–object / culture–nature / word–world distinctions.[26]

That Bohr subscribed to some sort of realism is also supported by his practice of science. A particularly poignant example of how different philosophical positions guided the efforts of different segments of the physics community during the 1920s is given by considering a range of reactions to the notion of "wave/particle duality". These reactions constitute the twentieth-century contribution to a long historical debate about the nature of light.

To say that light consists of particles is to insist that light consists of localized object that occupy a given location at each moment in time. On the other hand, to say that light consists of waves is to insist that light consists of objects with extension in space, occupying more than one position at any moment of time, like ocean waves that move along a stretch of beach; and furthermore, different waves can overlap and occupy the same position at any moment of time, unlike particles. Obviously, the concepts of "wave" and "particle" are mutually exclusive: an object

is either localized or it is extended, it can't be both. And yet, early twentieth-century experiments seemed to indicate that light behaves as a wave under certain experimental conditions, and as a particle under a mutually exclusive set of experimental conditions. This result was surprising since in the latter part of the nineteenth century the wave theory of light was well confirmed by both theoretical (Maxwell's electromagnetic theory) and experimental (diffraction and interference effects) considerations. Hence, a community-wide struggle ensued to resolve this paradox.

Classical realists hoped to resolve the paradox by finding some unifying explanation. Could it be that all objects are ultimately waves, but that on certain scales they look like particles? Another type of response came from the positivists/instrumentals who, like Heisenberg, put their faith in the mathematical formalism itself and saw the efforts to assign appropriate visualizable concepts to the mathematics as specious. While this seemed to be a neat and pragmatic solution to some physicists, others were not so willing to give up on interpretation and meaning.

Bohr's affinity for some kind of realistic interpretative stance led him to continue to seek out a solution to this paradox. Bohr participated with a tenacious passion in the debate. If Bohr had adopted an antirealist attitude it is doubtful that he would have found it necessary to develop an entirely new approach for understanding the role of descriptive concepts in science, which became the basis for Complementarity, and ultimately the so-called Copenhagen interpretation of quantum mechanics. Clearly, interpretative stances matter in the construction of scientific theories.

A few more historical details may be illuminating here. In 1924, Bohr wrote a paper with Kramers and Slater that put forth the radical conjecture that perhaps the most sacred principle in all of physics – the conservation of energy – would have to be sacrificed at the atomic level in order to find a satisfying resolution of the wave/particle duality paradox. Surely an instrumentalist or a die-hard antirealist would not have gone this far in attempting to explain the applicability of dual representations. The trio quickly retracted this proposal as soon as contrary empirical evidence came to light, but Slater never forgave Bohr for convincing him to go along with such a radical proposal. Bohr then adopted a new approach that entailed the examination of the circumstances under which these characteristics are manifest (they only appear under mutually exclusive circumstances), and consequently to an examination of the context-dependence of descriptive concepts.[27] Complementarity's development was contingent on certain realist commitments on Bohr's part. Otherwise, Bohr would have been content with the use of alternative descriptions (wave and particle) as evidenced by Heisenberg's instrumentalist stance.

Furthermore, there is important historical evidence that shows that Bohr strongly disagreed with Heisenberg about the importance and interpretation of wave/particle duality. Bohr and Heisenberg went off on separate vacations and developed the framework of Complementarity and the Uncertainty Principle, respectively; upon

returning to Copenhagen, Bohr passionately criticized Heisenberg's derivation of the Uncertainty Principle for its gross neglect of the centralness of wave/particle duality for an appropriate analysis.[28]

Bohr's interpretative framework deviates in a unique and nontrivial fashion from classical correspondence or mirroring theories of science. For Bohr, the paradox is resolved as follows: "wave" and "particle" are classical descriptions that refer to different mutually exclusive phenomena, and not to independent physical objects. He emphasized that this saved the theory from inconsistencies since it was impossible to observe particles and wave behaviors simultaneously since mutually exclusive experimental arrangements are required.

Ambiguity and paradox do not find a Newtonian/Cartesian resolution in this post-Newtonian framework. No final unifying reductionistic explanation is offered; only contextual understanding, located knowledges are obtained from the multiple contestations of the assumption of an inherent/fixed/universal/Cartesian subject–object distinction. The ambiguity is only temporarily, contextually decided, and therefore, descriptive characterizations do not signify properties of abstract objects or observation-independent beings, but rather describe the "between of our intra-actions" as it is marked by particular constructed delineations. (Since there is no sense of two things to interact, I have introduced the term "intra-action" to avoid reinscription of the contested dichotomy.) In other words, measurements of the values of the well-defined variables are attributable to the phenomenon as a particular instance of wholeness, the fully contextual be-in' where the matter and meaning meet.

6. AGENTIAL REALISM: THE FRAMEWORK

> Throughout the field of meanings constituting science, one of the commonalities concerns the status of any object of knowledge and of related claims about the faithfulness of our accounts to a "real world", no matter how mediated for us and no matter how complex and contradictory these worlds may be (Haraway, 1991, 197)

In addition to the question of interpretative stances in science studies, agential realism provides a framework for addressing broad epistemological and ontological issues. In this section I develop a few key points that are relevant to the issues I will address in the next section:[29] (1) agential realism grounds and situates knowledge claims in local experiences: objectivity is literally embodied; (2) agential realism privileges neither the material nor the cultural: the apparatus of bodily production is material-cultural, and so is agential reality; (3) agential realism entails the interrogation of boundaries and critical reflexivity; and (4) agential realism underlines the necessity of an ethics of knowing.

(1) *Agential realism grounds and situates knowledge claims in local experiences: objectivity is literally embodied.*

On the one hand, feminists and other Enlightenment critics have expressed skepticism towards objectivism, especially

[t]he idea of a basic dichotomy between the subjective and objective; the conception of knowledge as being a correct representation of what is objective; the conviction that human reason can completely free itself of bias, prejudice, and tradition; the ideal of a universal method by which we can first secure firm foundations of knowledge and then build the edifice of a universal science; the belief that by the power of self-reflection we can transcend our historical context and horizon and know things as they really are in themselves (Bernstein, 1983, 36).

In the post-Kuhnian era in which we live, the arguments against objectivism have been robust and extensive, reaching across disciplinary boundaries and out into the world beyond the academy, so that few scholars currently find it tenable to subscribe to the set of Enlightenment doctrines outlined above. Enlightenment defenders are hard-pressed to show how objectivism can bootstrap its way out of the murky waters of spacetime contingencies. Ironically, mainstream anti-Enlightenment theorists, including Derrida, Foucault, and Lyotard, have ignored crucial social markers such as gender and race in their critiques of the universalizing tendencies characteristic of the Enlightenment project. However, it is not only the limitations of these critiques that have concerned feminists, but their thoroughgoing rejection of the entire set of Enlightenment goals as well. Feminist theorists have taken exception with anti-Enlightenment scholarship that abandons the possibility of positive epistemologies in their embrace of interpretationism, relativism, and strong social constructivism.[30]

Haraway's theory of situated knowledges presents a direct challenge to the objectivist "view from nowhere", the "godtrick" of infinite passive vision, and the equally irresponsible relativist "view from everywhere", posing embodied sight – the view from somewhere, along with the responsibility that that entails – as the key to feminist objectivity. According to Haraway:

There is no unmediated photograph or passive camera obscura in scientific accounts of bodies and machines; there are only highly specific visual possibilities, each with a wonderfully detailed, active, partial way of organizing worlds. ... Understanding how these visual systems work, technically, socially, and psychically, ought to be a way of embodying feminist objectivity (1988, 583).

Agential realism gives us a technology of embodiment (Barad, 1996). Recall that concepts obtain their meaning by reference to a particular apparatus marking the placement of a constructed boundary between the "object" and the "agencies of observation". And in turn, the point of reference for objective description of phenomena is "from permanent marks ... left on bodies which define the experimental conditions." Therefore, bodies which define the experimental conditions serve as both the endpoint and the starting point for objective accounts of our intra-actions. In other words, *objectivity is literally embodied.* According to agential realism, knowledge is always a view from somewhere – objective knowledge is situated knowledge.

(2) *Agential realism privileges neither the material nor the cultural: the apparatus of bodily production is material–cultural, and so is agential reality.*

While theoretical constructs are not to be understood as representing transparently given observation-independent properties possessed by independent material objects/beings as they exist in isolation from all observational interactions,

neither are we to interpret these constructs as artifacts of the observational process, purely discursive gestures imprinted on the blank slate of passive matter. As Bohr tell us:

> These problems were instructively commented upon from different sides at the Solvay meeting.... On that occasion an interesting discussion arose also about how to speak of the appearance of phenomena.... The question was whether, as to the occurrence of individual effects, we should adopt a terminology proposed by Dirac, that we were concerned with a choice on the part of "nature" or, as suggested by Heisenberg, we should say that we have to do with a choice on the part of the "observer" constructing the measuring instruments and reading their recording. Any such terminology would, however, appear dubious since, on the one hand, it is hardly reasonable to endow nature with volition in the ordinary sense, while, on the other hand, it is certainly not possible for the observer to influence the events which may appear under the conditions he [*sic*] has arranged. To my mind, there is no other alternative than to admit that, in this field of experience, we are dealing with individual phenomena and that our possibilities of handling the measuring instruments allow us only to make a choice between the different complementary types of phenomena we want to study (Bohr, 1949, 223).[31]

There are three important points that we can take from this passage: (i) nature has agency, but it does not speak itself to the patient, unobtrusive observer listening for its cries – there is an important asymmetry with respect to agency: we do the representing, and yet (ii) nature is not a passive blank slate awaiting our inscriptions, and (iii) to privilege the material or the discursive is to forget the inseparability that characterizes phenomena.

As evidenced in the above quote, when Bohr and other physicists engaged in dialogue about quantum theory they spoke about the "choice made on the part of the experimenter," as if the experimenter is a liberal humanist actor of individual will.[32] There is no reference to the social dimensions of scientific knowledge production. (It is interesting to note though that Bohr does acknowledge the role of linguistic constraints.) However, without intending any anachronistic projections, it must be the case that material–semiotic apparatuses are fully cultural (i.e., social, linguistic, historical, political, etc.) frameworks, not the result of individual will, since reproducibility and unambiguous communication are the criteria for objectivity. That is, scientists make meanings within specific communities, they do not do so autonomously. Therefore, according to agential realism, the apparatus that is theorized must be a multidimensional material–cultural framework.

Furthermore, agential realism provides an account of the simultaneously material and cultural nature of the ontology of the world. Saying that something is socially constructed doesn't mean that it isn't real – on the contrary, according to agential realism, reality is itself material-cultural.[33] There is no opposition here between materiality and social construction: constructedness does not deny materiality. *The materiality of the body is not dissipated by its constructedness since reality is constituted by the "between", the inseparability of nature-cultural / world–word / physical–conceptual / material–discursive.* Culture does not displace or replace nature, but neither do things exist outside of culture. Phenomena are material–cultural be-in's. Haraway makes a similar point, I think, in designating objects as "material–semiotic actors". She uses this term "to portray the object of knowledge as an active, meaning-generating part of the apparatus of bodily production, without ever implying the immediate presence of such objects.... Boundaries are

drawn by mapping practices; 'objects' do not preexist as such. Objects are boundary projects" (Haraway, 1988, 595). In other words, the apparatus of bodily production, *qua* agencies of observation, are not separable from phenomena.

(3) *Agential realism entails the interrogation of boundaries and critical reflexivity.*

Wholeness, according to agential realism, does not signify the dissolution of boundaries. On the contrary, boundaries are necessary for making meanings. Theoretical concepts are only defined within a given context, as specified by constructed boundaries. Wholeness is not about the prioritizing of the innocent whole over the sum of the parts; wholeness signifies the inseparability of the material and the cultural. Wholeness requires that delineations, differentiations, distinctions be drawn; differentness is required of wholeness. Utopian dreams of dissolving boundaries are pure illusion since by definition there is no agential reality without constructed boundaries. There are two common ways to attempt to deny responsibility for boundaries: (1) claim that they are natural, or (2) claim that they are arbitrary partitionings of a holistic oneness, existing outside of human space and time. In contrast, agential realism explicitly shows that boundaries are interested instances of power, specific constructions, with real material consequences. There are not only different stakes in drawing different distinctions, *there are different ontological implications.*

Furthermore, boundaries are not fixed. Productive and creative tensions are set up in consideration of different possible placements of agentially situated cuts. Consideration of mutually exclusive intra-actions, constituting opposing shifts in the conceptual terrain, reminds us that descriptive concepts do not refer to an observer-independent reality, but to phenomena. In fact, descriptions reflect back upon the specification of boundaries, since descriptions refer to phenomena and boundaries are in phenomena (i.e., the conceptual scheme is tied to the physical apparatus and the descriptions refer to the phenomenon, which by definition includes the apparatus; therefore the description refers back to the constructed conceptual scheme). The placement of the boundary becomes part of what is being described: human conceptual schema are part of the quantum wholeness. Descriptions of phenomena are reflexive, and the shifting of boundaries constitutes a meta-critique.

The acknowledgement and interrogation of context is common to many feminist epistemologies. For example, both Longino's theory of contextual empiricism and Harding's theory of strong objectivity call for a critical examination of background assumptions. Harding writes:

> In an important sense, our cultures have agendas and make assumptions that we as individuals cannot easily detect. Theoretically unmediated experience, that aspect of a group's or an individual's experience in which cultural influences cannot be detected, functions as part of the evidence for scientific claims. Cultural agendas and assumptions are part of the background assumptions and auxiliary hypotheses that philosophers have identified. If the goal is to make available for critical scrutiny all the evidence marshaled for or against a scientific hypothesis, then this evidence too requires critical examination within scientific research processes (1991, 149).

Agential realism includes practice within theory: theory is epistemologically and ontologically reflexive of context. Contrary to traditional views of theory that take

the actual practice of measurement to be outside of theory, and according to the logical positivist/empiricist program which assumes that measurements transparently adjudicate among theories, Bohr's philosophy-physics entails a reconceptualization of science that places the discourse on science into scientific discourse. That is, *phenomena are the embodiment of cultural practices within theory*. I suspect that the reflexive implications are a root cause of Bohr's marginalization within the physics community (see Barad, 1995 for more details).

(4) *Agential realism underlines the necessity of an ethics of knowing.*

According to agential realism, reality is not independent of our explorations of it – both epistemologically *and* ontologically speaking. Focusing on the ontological as well as the epistemological is crucial to intra-acting responsibly within the world. Knowledge projects entail the drawing of boundaries, the production of phenomena which are material–cultural intra-actions. That is, our constructed knowledges have real material consequences. And therefore, agential realism calls for direct accountability and responsibility. It is to remind us of this fact that the adjectival form of the word "agency" modifies and specifies the form that realism takes here, in defiance of traditional forms of realism that deny any active participation on the part of the knower. Agency is a matter of intra-acting, that is, agency is an enactment, it is not something someone has.

We need to understand the technologies by which particular social constructions have real material consequences. According to agential realism, the full apparatus of bodily production must be theorized as well – the consideration of acontextual variables will give inadequate results. Think again of the existence of wave phenomena in the context of a particular apparatus of bodily production; particle phenomena are tied to a mutually exclusive apparatus. Quantum physics can account for the phenomenon that exists in a particular context if and only if the apparatus of bodily production is included in the calculation. Agential realism provides an understanding of the possible dynamical intra-actions of nature–culture as ontological be-in's, thus helping us to theorize the material consequences of constructing particular apparatuses of bodily production. Knowing involves denaturalizing, multiply contesting and destabilizing the existing apparatus to refigure boundaries. This will have real material consequences, so that agential realism underlines the requirement for an ethics of knowing.

7. AGENTIAL REALISM AND SCIENCE STUDIES

> The notion of complementarity, Bohr also wants to say, can be seen to arise out of the nature of our consciousness of what is "other" to us, out of the unresolvable tension between content and form, between reality and concept, and between theory and experience. Our representations of reality do not so much involve a privileged mental mirroring of external reality, in which object and subject are absolutely distant from each other, as a successful compromise between language and activity.... Yet for Bohr the relationship between word and world is not seen as entirely relative, with the implication that our words have no anchorage in world; instead given the nature of our consciousness of what is demonstrably "other" to us, a relationship between word and world is accepted as necessarily denying complete resolution (Honner, 1987, 103).

As a scientist I have been very interested in feminist science studies in part because the scholars in this field, many of whom are scientists as well, have resisted the polarization often found in contemporary discussions about the nature of science as posed by the more traditional and monodisciplinary approaches. Evelyn Keller identifies two noncommunicating discourses about science,

> ... one an increasingly radical critique that fails to account for the effectiveness of science, and the other a justification that draws confidence from that effectiveness to maintain a traditional, and essentially unchanged, philosophy of science. What is needed is a way of thinking and talking about science that can make sense of these two very different perspectives – that can credit the realities they each reflect and yet account for their differences in perception (Keller, 1985, 6).

I think these tensions are quite productive and, in my opinion, Keller's challenge marks one of the most important issues for contemporary science studies.

If the "discovery model" of science, that sees the production of scientific knowledge as a one-actor show – nature at center stage with a passive audience of observers patiently looking on – is no longer acceptable, and neither is some extreme version of social constructivism that presents science as an arbitrary compendium of power-laden rhetorical moves, then is it possible to give a detailed understanding of the interaction of nature and culture in the production of scientific knowledge? Agential realism provides a framework that can be useful for retheorizing a range of issues generated by reliance on classical epistemologies and ontologies. In this section, I will explore the implications of agential realism for science studies. I have in mind the following questions: How can we reconcile the claim of science studies scholars that scientific knowledge is a socially constructed product that is conceptually, methodologically, and epistemologically allied along particular axes of power with both the liberatory and oppressive interventions that are possible because of the reliability of empirically adequate scientific knowledges? What, if anything, can be said about the ontology of our world through our investigations of it? Is there a notion of realism that is consistent with the assertion that scientific knowledge claims are culturally specific?

The scientific method, which was our Enlightenment birthright, promised to serve as a giant distillation column, removing all cultural influences, and allowing patient practitioners to collect the pure distillate of Truth. The transparency of Newtonian physics to the process of measurement grew out of and helped reinforce this cultural milieu of objectivism that made the successes of science unparadoxical: science works because scientists are able to obtain the facts about the world as it exists independently of us human beings. The Enlightenment notion of science is premised on a separation between knowing subjects and observation-independent objects. Agential realism challenges this conceptualization of science on epistemological and ontological grounds.

According to agential realism, scientific concepts obtain their meaning by reference to a particular physical apparatus marking the placement of an agentially constructed cut between the "object" and the "agencies of observation". In turn, the point of reference for objective description of phenomena is "from permanent marks ... left on the bodies which define the experimental conditions"[34] (Bohr,

1963c, 3). Therefore, bodies serve as both the endpoint and starting point for objective accounts of our intra-actions. In other words, agential realism gives us an embodied account of objectivity.

Scientific results are not reproducible because we are able to measure the observer-independent properties of an independent reality. Reproducibility is possible because scientific investigations are embodied, grounded in experience, in praxis. Reproducibility means the possibility of the reproduction of phenomena, and phenomena are written on the "body"; phenomena are the place where matter and meaning meet. Reproducibility of phenomena does not require or serve as proof for access to the transcendent. "The overall force of Bohr's argument is that we are without absolute foundation in our participation in the world, despite the acceptance that our language works by being anchored in everyday experience of reality" (Honner, 1987, 222). Reproducibility of phenomena is not innocent – it depends upon the choice of some constructed cut for which the ambiguity is only temporarily, contextually decided in such a way as to lend meaning to certain concepts, at the exclusion of others. Reproducibility is not a filter for shared biases; the apparatus of bodily production is culturally situated. The scientists marking off the boundaries are marked by the cultural specificities of race, history, gender, language, class, politics, etc. In stark contrast to the classical framework, there is a sense of agency and therefore accountability. Since reproducibility is the cornerstone of Western science, in the context presently under discussion, science has meaning, but not in any classical sense.[35] According to agential realism, *science is movement between meanings and matter, word and world, interrogating and redefining boundaries, a dance not behind or beyond, but in "the between", where knowledge and being meet.*

Scientific knowledge is not an arbitrary construction independent of "what is out there", since it is not separate from us; and given a particular set of constructed cuts, certain descriptive concepts of science are well-defined and can be used to achieve reproducible results. However, these results cannot be decontextualized. Scientific theories do not tell us about an independent reality; scientific concepts are not simple namings of discoveries of objective attributes of an independent Nature with inherent demarcations. Scientific concepts are not innocent or unique. They are constructs which can be used to describe "the between", rather than some independent reality. (Why would we be interested in such a thing as an "independent reality" anyway? We don't live in such a world.) The point is that phenomena constitute reality. That is, reality itself is material–cultural. And according to agential realism, scientific knowledges are situated knowledges describing *agential* reality. My revision of an important quote by Niels Bohr goes like this: "It is wrong to think that the task of physics is to find out how nature is. Physics concerns what we can say about [our intra-actions within] nature." *We are in reality, we must be in our theories.* In other words, scientific theories describe agential reality – which is just what we are interested in (we don't live in a transcendent reality). For scientific theories to be able to describe agential reality, scientific knowledge must take material–cultural factors into account since they are in agential reality, otherwise

we would not expect scientific knowledge to produce empirically adequate accounts of our intra-actions within nature. Reliability is not premised on access to the transcendent, but on the grounding of practice within theory. (The nonclassical epistemology and ontology have removed the paradox of the classical position which sees the reliability of scientific theories as contingent upon objective discoveries of an independent reality.) Consideration of mutually exclusive sets of concepts produce crucial tensions and ironies which underline the point that *it is the fact that scientific knowledge is socially constructed that leads to reliable knowledges about reproducible phenomena – which is just what we are interested in.* Therefore, the understanding that science as a social practice is conceptually, methodologically, and epistemologically allied along particular axes of power can indeed be reconciled with the fact that scientific knowledge is empirically adequate, that it provides effective interventions which may be used towards either regressive or liberatory purposes.

It is not that we attempt to view nature through the lens of culture with an optics that has varying degrees of transparency or opaqueness. We do not try to fit our theories to reality by probing the fixed boundary between nature and culture. Phenomena constitute our ontology. And since scientific concepts can be used to describe phenomena and phenomena are not "out there", but are material-cultural be-in's, agential realism provides us with a form of realism that is compatible with social constructivism. Agential realism is a form of social constructivism that is not relativist, does not reduce knowledge to power plays or language, and does not reject objectivity.

8. CONCLUSIONS

> So, I think my problem and "our" problem is how to have *simultaneously* an account of radical historical contingency for all knowledge claims and knowing subjects, a critical practice for recognizing our own "semiotic technologies" for making meanings, *and* a no-nonsense commitment to faithful accounts of a "real" world, one that can be partially shared and friendly to earth-wide projects of finite freedom, adequate material abundance, modest meaning in suffering, and limited happiness (Haraway, 1991, 187).

Agential realism denies the innocence of naive realism; instead, it entails a conscious, critical reflexivity. Dualisms, binary oppositions, dichotomies, and other demarcations are not secured with natural status as Cartesian cuts which form the foundation of all knowledge – not even in physics. The lines drawn are power-laden epistemological moves with stakes in a given conceptual scheme. This doesn't mean that we can't justify drawing lines, or that crafted conceptual schemes are unusable. Just because science is exposed as being socially constructed doesn't mean that it doesn't work. And empirical adequacy is not an argument that can be used to silence charges of constructivism. But neither is constructivism a proof of epistemological relativism. I have argued that reliable theories about our intra-actions are necessarily socially constructed theories with real material consequences. We need knowledge systems that are both reliable and accountable guides to action. Agential realism creates an alternative to objectivist accounts of

knowledge production that deny the situated nature of knowledges and social constructivist accounts that do not address the effectiveness of knowledge systems.

Agential realism is not a call for feminists and others to bow down once again to the hegemony of science in finding a new epistemology. On the contrary, agential realism undermines the hegemony of science (though not its effectiveness). Agential realism insists that science incorporate a reflexive critical discourse, like all other human endeavors. Bohr argued that quantum physics, considered by many to be the most highly esteemed field of science, requires a new framework for understanding the role of descriptive concepts in scientific knowledge production. The notions of wave and particle deconstruct one another, exposing the limitations of the classical framework. There is irony, though perhaps little surprise, in the fact that our interactions with light – oh light! that ever resilient metaphor for knowledge illuminating the dark terrain of ignorance – plays a central role in undermining the hegemony of Newtonian physics, that bright star of the En-lightenment, deconstructing the objective–subjective and nature–culture dualisms that have plagued many attempts to understand the nature of scientific knowledge.

What I am proposing is not some holistic approach in which subject and object reunite into some apolitical relativized whole, but a theory which insists on the importance of constructed boundaries and also the necessity of interrogating and refiguring them. The intra-action involving the subject–object problematizes natural, pure, and innocent separations, but not in a way which reaches for the rapid dissolution of boundaries. Boundaries are not our enemies; they are necessary for making meanings, but this does not make them innocent. Boundaries have real material consequences – cuts are agentially positioned and accountability is mandatory. The shifting of boundaries often helps bring to the surface questions of power which the powerful often try to submerge. Agential realism insists that mutually exclusive, shifting, multiple positionings are necessary if the complexity of our intra-actions are to be appreciated.[36] Multiple contestations of agentially positioned boundaries keep concepts alive, and protects them from reification and petrification. Our goal should not be to find less false boundaries for all spacetime, but reliable, accountable, located temporary boundaries, which we should anticipate will quickly close in against us. Agential realism will inevitably be a casualty of its own design, but I suggest that there is power there presently for some of our purposes.[37] Agential realism involves located or situated knowledges (Haraway, 1988), knowledges that reject transcendental, universal, unifying master theories in favor of understandings that are embodied and contextual.

Who are the agents in agential realism? The history of science parallels the history of knowledge in other arenas: the powerful effectively portray their own knowledge systems as universal, denying their own agency. Within this tradition, agency has been an issue quite separate from authorship. Rivalries over primary authorship are common in the history of science, but what is at stake is cleverness and ingenuity; what is "discovered" is presumed unmarked by its "discoverer". The claim is that the well-prepared scientist can read the universal equations of Nature that are inscribed on G–d's blackboard: Nature has spoken. The paradox is that the

objects being studied are given all the agency, even and most especially when they are seen as passive, inert things, culture-free and existing outside of human space and time, moving aimlessly in the void. Completing this Enlightenment scenario, are the passive human observers who are without agency. The overdetermination of Enlightenment discourse is revealed in the juxtaposition of this mythology with the liberal humanist story that provides man with individual will and dominion over nature.

The nature–culture and object–subject dualisms are constructed cuts passed off as inherent and fixed in the service of this legacy. Agential realism makes other moves: shifting and destabilizing boundaries. Here knowledge comes from the "between" of nature–culture, object–subject, matter–meaning. The Cartesian split between the agencies of observation and the object is a classical illusion. Agency cannot be designated as residing in one or the other in isolation. The observer does not have total agency over passive matter – not any representation of reality will do – since not any result one can think of is possible: the world "kicks back". Neither does the object have total agency, whispering its secrets, mostly through the language of mathematics, into the ear of the attentive scientist – knowledge is not so innocent; it doesn't "just come out that way" all by itself. Nature is neither a blank slate for the free-play of social inscriptions, nor some immediately present, transparently given "thingness". Agential realism acknowledges the agency of both subjects and objects without pretending that there is some utopian symmetrical wholesome dialogue, outside of human representations. Science is not the product of some interaction between two well-differentiated entities: nature and culture, since it flies in the face of any matter–meaning dichotomy, like an electron that tunnels through boundaries set up to confine its motion. Meaning and matter are more like interacting excitations of non-linear fields – a dynamic, shifting dance we call science.[38]

Phenomena are the intra-actions of knowledge and being, word and world, culture and nature. Phenomena are material-cultural be-in's. Agential realism relies on a non-classical ontology. The material is not fixed and prior to discursive signification, but in it. Jeanette Winterson writes in her recent novel *Written on the Body*: "That is how I know you. You are what I know" (Winterson, 1992, 120). Intra-acting is an activity that theorizes the mechanics of an embodied objectivity. In our attempt to understand we actively participate within reality. *Realism is not about representations of an independent reality, but about the real consequences, interventions, creative possibilities, and responsibilities of intra-acting within the world.*

Finally, materiality matters: there are social and material reasons for knowledge claims – the intra-actions of the material and the discursive are the technologies of embodied objectivity – and socially constructed knowledges have real material consequences. These conceptions of materiality are opposed to the immediacy of matter in naive realist accounts and its neglect in some social constructivist accounts. It seems to me that giving up on realism would be as hasty as giving up on objectivity. Feminists have interrogated, redefined, and retheorized objectivity; agential realism is an attempt to formulate a feminist notion of realism. Agential realism goes beyond the recognition that there are material and cultural reasons for knowledge claims, beyond the reconceptualization of description in knowledge

systems, to providing us with a positive sense of the ontology of our world and some important clues as to how to intra-act responsibly and productively within it.

Judy Grahn suggests that: "To understand, to get to the basis, the root or hidden meaning, is the wrong tool to bring" to our own work. "Perhaps interstand [or better yet intra-stand] is what we do, to engage with the work, to mix with it in an active engagement, rather than 'figuring it out'. Figure it in" (Grahn, 1989, 39). Knowledges are not innocent representations, but intra-actions of natures–cultures: knowledge is about meeting the universe halfway.

Pomona College,
Claremont, CA

ACKNOWLEDGEMENTS

The original version was presented at the Pew Gender and Science Workshop, Lake Arrowhead, CA, September 1991. Successive versions were presented at numerous conferences and public lectures. I am grateful to Ruth Wilson Gilmore, Donna Haraway, Sandra Harding, Martin Krieger, Helen Longino, Lynn Hankinson Nelson, Jennifer Rycenga, Sharon Traweek, and Roanne Wilson for their insightful comments and support.

NOTES

[1] A less obvious point is that the success of scientific theories is not automatic for realists either, as Laudan (1981) and Fine (1984) argue.

[2] Cushing asserts that "realism is in double jeopardy", in the sense that although Bohm's interpretation is realist, he tags Bohr's interpretation of quantum physics as antirealist, and furthermore, the existence of this concrete example of underdetermination means that it would be very difficult to make the case for realism. Although I will be arguing here for a realist interpretation on the part of Bohr, this divergence in and of itself does not weaken the underdetermination aspect of Cushing's argument. (There are a few independent issues however. One is the fact that the empirical equivalence of these theories depends upon the resolution of the measurement problem for the Copenhagen interpretation (see fn. 6) since rigorously speaking without such a resolution the Copenhagen interpretation does not offer definite predictions (see Albert, 1992). And of course, it still remains to be seen whether Bohm's theory and the Copenhagen theory are empirically coincident in all respects.)

[3] This is not a circularity. As I will explain later, it is indicative of a critical reflexivity.

[4] The destabilization of liberal humanist conceptions of identity that follow from the framework of agential realism will not be my focus here. My focus here will be primarily on science. For more details on agential realism and identity see Barad, forthcoming.

[5] The collected volumes of Bohr's writings have been made available thanks to Rosenfeld, (1972–).

[6] While physicists talk of *the* Copenhagen interpretation, in one sense there are really many Copenhagen interpretations, or to put it another way there is no well-defined, coherent, and complete Copenhagen interpretation. This is due to the fact that the physicists who are seen as the contributors had strong philosophical/interpretative differences, so that what is taken to be *the* Copenhagen interpretation is actually a superposition of the views of Bohr (complementarity), Heisenberg (uncertainty), Born (probability), and Von Neumann (collapse), to name a few of the key players.

[7] For more details see Cushing, 1994. (Although Bohr's philosophy-physics is not a primary focus for Cushing, I note that my reading of Bohr diverges substantially from Cushing's. As I specify in more

detail later, my reading has much more overlap with interpretations presented by a number of Bohr scholars.)

[8] There are an increasing number of quantum textbooks that do not mention any of Bohr's contributions to the field (except for reference to his pre-quantum theory atomic model). That is, there is often no mention of his principle of correspondence and the role it played in the development of the quantum theory, or Complementarity and its importance to an understanding of quantum theory.

[9] For Bohr, Complementary means simultaneously necessary and mutually exclusive (as explained in detail in the next section. NB: I capitalize 'complementary' when it is used in Bohr's sense of the term). See Bohr (1963b) for examples for this approach. An attempt by Bohr to resolve the vitalism–mechanism debate in biology failed because he assumed, from his limited technological perspective, that the conditions for examining the underlying mechanics of life processes and the conditions for maintaining the life of the specimen under investigation were mutually exclusive.

[10] Although one is free to give antirealist interpretation of Newtonian physics, the "classical realist" one articulated here is particularly seductive to our Enlightenment intuitions, and I have heard variations of this classical realist tenet espoused time and again to students in undergraduate physics classes. (It is of course ironic to attribute a realist stance towards the physics of one who was unwilling to feign any hypothesis, but not many students would pick up on this since physics courses overwhelmingly lack any overt discussion of the different interpretative stances with regard to science. See Barad (1995) for the pedegogical implications of this widespread inattention to metatheoretical issues and the lack of critical reflexivity.)

[11] A re-visioning of the nature of light is common to both of the major conceptual revolution of twentieth century physics: special relativity and quantum theory. Special relativity will not be considered in this paper, but a few words to distinguish some of the more popular implications of this theory from quantum mechanics may be helpful to some readers. The special theory of relavity is based on the empirically verified invariance and finiteness of the speed of light (1/speed of light = 1/constant = $1/c \neq 0$). Einstein transformed Galilean relativity into a new theory of relativity, redesignating certain previously held invariant quantities as relative and vice versa. (Einstein had thought of calling this theory "the theory of invariances", and he may have been better off doing so given the political climate in Europe during the first half of the 20th century.) The theory of relativity gives the measurement process some limited visibility: concepts such as "time" and "length" are defined relative to a particular frame of reference in which the measurements are performed. (It is not that time appears to slow down; time is what you measure with a clock.) The theory of relativity may have undermined the universality of certain concepts, but the assumption that measurements are continuous and determinable is never questioned. That is, according to the special theory of relativity there still is a well-defined separation of object and measuring instrument, i.e., a clear subject/object distinction is preserved. The properties measured are attributable to an independent object as measured relative to a particular frame of reference. (The frame of reference simply specifies which "time" we are talking about, that is, what we mean by "time" in each case.)

[12] It is important to note that the fact that Newtonian physics "works" in the macroscopic domain does not mean that the assumptions of measurement transparency are true in that domain. On the contrary, this simply explains why the assumptions lay hidden for centuries. That is, the fact that Newtonian physics makes predictions that are approximately the same as those made by quantum theory in the macroscopic domain is due to the fact that in that regime the ratio of Planck's constant to the mass of the particle is smaller than the accuracy required of the macroscopic situation in question – but it is *not* zero. This is why Bohr refers to the general epistemological lessons of quantum theory.

[13] A rough, intuitive picture is the following: think of catching a ball, the relative amount by which your arm moves back is an indication of the momentum of the ball.

[14] I have chosen to use the term 'constructed' instead of Bohr's term 'arbitrary' for two reasons. First of all, 'arbitrary' is misleading since the cut is not totally arbitrary in that the cut must be made in such a way that the measuring device is always macroscopic (this is necessary since the use of classical concepts is predicated on a subject/object split). Secondly, the term 'arbitrary' carries misleading connotations such as the inappropriate associations of relativism. The point that I think Bohr is out to emphasize in using the term 'arbitrary' is that since there is no inherent/Cartesian distinction some non-inherent distinction still must be drawn. Since the choice of a conceptual apparatus necessarily draws

this distinction, I will use the term 'constructed' in the hope that this term will connote agency. The full contrast is that classical physics is premised on an inherent/naturally occurring/fixed/universal/Cartesian distinction while quantum physics requires constructed/agentially positioned/movable/local/"Bohrian" cuts, positioning Bohr as Descartes counterpart.

[15] Another way of expressing this quantum quandary is by noticing that this means that the act of measuring can be accounted for only if the measuring device is itself treated as an object, defying its purpose as a measuring instrument.

[16] See Barad (1995) for a more detailed discussion of this example.

[17] "Bohr's provocative tendency, especially in earlier writings, to 'emphasize the subjective character of all experience' (Bohr, 1963a, 1) brought his entire interpretation of quantum theory into peril" (quoted in Honner, 1987, 65), parallel to terminological choices made by some science studies scholars early on that proved equally rhetorically disadvantageous.

[18] Bohr interchanges the phrases "language of everyday experience" and "language of classical physics". The connection for Bohr is that everyday experiences take place within the macroscopic realm to which the language of classical physics is applied. However, he does suggest that the language of everyday experience may include "suitable generalizations" of the language of classical physics.

[19] Bohr: "It is just arguments of this kind which recall the impossibility of subdividing quantum phenomena and reveal the ambiguity in ascribing customary physical attributes to atomic objects" (Bohr, 1963b, 51).

[20] This detailed mapping of the relationship between classical concepts and phenomena is meant to clarify Bohr's position with respect to the necessity of using classical concepts in the description of quantum phenomena. Confusion about this issue is widespread in the literature. Many physicists trying to understand Bohr's interpretative framework have accused Bohr of conservatism with respect to the future development of physical theories: why they asked should we limit our descriptive concepts in this way? It is also not uncommon to find philosophers describing this aspect of Bohr's theory as Kantian. I hope that I have clearly communicated here why I think it is that Bohr was not denying the possibility for future creative developments in physics, nor was he advocating transcendental idealism in his insistence on the use of *empirically grounded* classical concepts *even* within a *nonclassical* framework (which is already admitting the possibility of the evolution of ideas). An important related fact is that Bohr offers the observation that "everyday" languages are based on subject–predicate forms (a point that he unfortunately makes without qualification); that is, everyday languages structurally assume subject–object distinctions. I believe that this a contributing factor to what is commonly described as the obscurity of Bohr's writings, since he uses many circumlocutions to try to talk about things that are not inherently structured along this distinction.

[21] See Keller's "Anomaly of a Woman in Physics" (1977) for one telling of a graduate school experience in the US that is typical in its discouragement of reflexivity and contemplation of interpretative questions in physics, though specific in its gendering.

[22] This quote is from Petersen, 1985, 302. Petersen goes on to say that Bohr had no use for an ontology. Perhaps Bohr didn't feel the need to articulate one, but this is not to say that he held a thorough-going pragmatic or positivist view. In fact, I will argue later in this section that Bohr had a realistic attitude towards wave-particle duality, for example, though his views diverged dramatically from classical realism. Honner (1987) also argues for a realistic interpretation and against pragmatic or positivist perspectives, although the version of realism that Honner ascribes to Bohr does not address the issue of a reference for our representations. Folse (1985) also advocates for an interpretation which sees Bohr as a realist, but Folse seems to take phenomena as the result of an underlying reality.

[23] Einstein *et al.*, 1935 and Bohr, 1935. In an article entitled "Discussion with Einstein on Epistemological Problems in Atomic Physics", for a volume honoring the epoch-making contributions of his long time friend Albert Einstein, Bohr quotes extensively from this particularly important passage of his 1935 paper (see Bohr, 1949, 234).

[24] I have presented what may seem like a pedantic analysis of Bohr's use of the term 'phenomenon' in this passage, but I do so because as of 1935 his use of this term was still somewhat inconsistent, and it is therefore crucial to justify by the context of his usage of this term that it indeed is consistent with the specific signification he assigns to it in his later writings. In fact, Bohr's usage of 'phenomenon'

to signify the wholeness in the interaction between "objects of investigation" and "agencies of observation" is consistent throughout this particular 1935 article.

[25] This fact motivates my introduction of the term 'intra-action' at the end of this section since phenomena are the instantiation of intra-actions.

[26] This criterion would apply as well to any suggestion of a Bohrian notion of anti-realism. In particular, realists cannot expect to rely on an independent external reality, but also antirealists would be hard pressed to argue against realism on the basis of some postulated inaccessible independent reality.

[27] This mutual exclusivity highlights the problematics of an instrumentalist stance for Bohr. How does the instrumentalist account for the non-arbitratriness of this feature? (What auxiliary criterion must be applied?)

[28] After a few weeks of intensive discussion, Heisenberg finally acquiesced to Bohr's point of view and added a postscript to his article on the uncertainty principle in which he states: "In this connection Bohr pointed out to me that I have overlooked essential points in some of the discussion of this work. Above all the uncertainty in the observation does not depend exclusively on the occurrence of discontinuities, but is directly connected with the necessity of doing justice simultaneously to the different experimental data which are expressed in the corpuscular theory on the one hand and the wave theory on the other [i.e., wave–particle duality]" (quoted in Murdoch, 1987, 51) Recent papers in quantum optics (e.g., see Scully *et al.*, 1991) give empirical evidence in support of Bohr's interpretation of the uncertainty principle over the one given by Heisenberg which is not consistent with these findings. NB: it is Heisenberg's analysis (without Bohr's corrections) that is taught to physics students. See Barad (1995) for more details. The divergence of Bohr's and Heisenberg's interpretations of the uncertainty principle highlights their philosophical (realist and instrumentalist, respectively) differences. The construction of scientific theories is influenced by philosophical attitudes.

[29] Other pivotal aspects of the framework of agential realism are developed in Barad, forthcoming. In particular, there is a more in-depth discussion of the issues of agency and identity. The fact that agential realism can be used to think about rather disparate issues from the destabilization of identity to the destabilization of science is not a matter of a more parallelism, but different instances of the same epistemological and ontological issues.

[30] For a more detailed discussion see Harding (1990) and other articles in *Feminism/Postmodernism*, ed. Nicholson.

[31] The positions that Heisenberg and Dirac articulate here are consistent with the former's instrumentalist leanings and the latter's traditional realist leanings.

[32] In a related fashion I have stayed away from Bohr's term "Complementarity" because of the associated connotations of liberal humanist conceptions of choice. Take the example of the complementary (intended here in the colloquial sense of the word) theory of genders where essentialized differences between men and women are theorized on a level playing field, denying the unequal power relations represented by unequal material conditions. Matrix theory (not the mathematical kind but the kind that comes from social theory) and other nonessentializing analytic moves fully deconstruct such liberal conceptualizations.

[33] To assert that we only get to study nature through the distorting lense of culture is to reinstate the privileged position of the transcendent once again, resulting in further classical epistemological astigmatism.

[34] Bohr makes direct note of this point himself: "the description of atomic phenomena has in these respects a perfectly objective character, in the sense that no explicit reference is made to any individual observer and that therefore ... no ambiguity is involved in the communication of information" (Bohr, 1963c, 3).

[35] Notice that experiments in some fields, like high energy physics, are rarely repeated due to constraints imposed by limited resources or other community priorities, but the issue here is not whether or not the results have actually been reproduced, the issue is the possibility of reproducibility due to the literal embodiment of objectivity. Also, note that reproducibility is still an issue for scientists studying chaotic systems (which are highly sensitive to initial conditions) in the sense that chaotic systems do not behave differently for different observers (it is just that it is very difficult, to start an experiment with the very same initial conditions, but simulations of chaotic systems are often reproduced). Other criteria delineat-

ing science (read "Western science") from nonscience have been offered (see Harding, 1993). This project of delineation is of course part and parcel of Western imperialism's focus on distinguishing "us" from "them". Nonetheless, this same distinction along these lines is extremely common in the science studies literature and it is therefore useful in this context.

[36] Kondo (1989) and Sandoval (1991) make a similar point. Anzaldúa (1987) theorizes the constructed nature of boundaries.

[37] Feminist scientists, economists, political scientists, historians, psychologists, geographers and literary critics are among those who have expressed seeing the utility of agential realism for their projects.

[38] "Tunneling" is a quantum phenomenon whereby classically confined particles escape. This is the result of the uncertainty principle and it explains many different physical phenomena such as nuclear decay, transistors, etc.

REFERENCES

Albert, David Z.: 1992, *Quantum Mechanics and Experience*. Cambridge, MA: Harvard University Press.

Anzaldúa, Gloria: 1987, *Borderlands/La Frontera*. San Francisco: Spinsters/Aunt Lute Book Co.

Barad, Karen: 1995, 'A Feminist Approach to Teaching Quantum Physics', in *Teaching the Majority: Breaking the Gender Barrier in Science, Mathematics, and Engineering*, edited by Sue V. Rosser. NY: Teachers College Press.

——: 1996, 'Getting Real: Technologies of Embodiment and Materiality', keynote address, Gender, Technology, Place Conference, Rutgers University, March 30, 1996.

——: forthcoming, *Meeting the Universe Halfway*, Book Manuscript.

Bernstein, Richard J.: 1983, *Beyond Objectivism and Relativism: Science, Hermeneutics, and Praxis*. Phila: U. of Penn. Press.

Bohm, David.: 1985, 'On Bohr's Views Concerning Quantum Theory', in *Niels Bohr: A Centenary Volume*, ed. French, A. P. and Kennedy, P. J. Cambridge, MA: Harvard U. Press.

Bohr, Niels: 1935, 'Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?', *Physical Review*, **48**, 696–702.

——: 1937, 'Causality and Complementarity', *Philosophy of Science*, **4**.

——: 1949, 'Discussion with Einstein on Epistemological Problems in Atomic Physics', in *Albert Einstein: Philosopher-Scientist*, ed. P. A. Schilpp. Evanston: Northwestern U. Press.

——: 1963a, *The Philosophical Writings of Niels Bohr, Vol. I: Atomic Theory and the Description of Nature*. Woodbridge, Conn: Ox Bow Press.

——: 1963b, *The Philosophical Writings Of Niels Bohr, Vol. II: Essays 1933–1957 on Atomic Physics and Human Knowledge*. Woodbridge, Conn: Ox Bow Press.

——: 1963c, *The Philosophical Writings of Niels Bohr, Vol. III: Essays 1958–1962 on Atomic Physics and Human Knowledge*. Woodbridge, Conn: Ox Bow Press.

Cartwright, Nancy: 1983, *How the Laws of Physics Lie*. New York: Clarendon Press.

Cushing, James T.: 1994. *Quantum Mechanics: Historical Contingency and the Copenhagen Hegemony*. Chicago: University of Chicago Press.

Einstein, A., Podolsky, B., and Rosen, N.: 1935, 'Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?' *Physical Review*, **47**, 777–780.

Feyerabend, P. K.: 1962, 'Problems in Microphysics', in *Frontiers of Science and Philosophy*, ed. Robert G. Colodny. Pittsburgh: U. of Pitt.

Fine, Arthur: 1984, 'The Natural Ontological Attitude', in *Scientific Realism*, ed. by J. Leplin. Berkeley: University of California Press.

Folse, Henry: 1985, *The Philosophy of Niels Bohr: The Framework of Complementarity*. NY: North-Holland.

Fulton, Alice: 1990. *Powers of Congress*. Boston: David R. Godine

Galison, Peter: 1987, *How Experiments End*. Chicago: The University of Chicago Press.

Grahn, Judy: 1989, *Really Reading Gertrude Stein*, Freedom, CA: Crossing Press.

Hacking, Ian: 1982, 'Experimentation and Scientific Realism', *Philosophical Topics*, **13**, 71–87.

Haraway, Donna: 1985, 'Manifesto for Cyborgs: Science, Technology, and Socialist Feminism in the 1980s', *Socialist Review*, **80**, 65–108, (reprinted in Haraway, 1991).

——: 1988, 'Situated Knowledges: The Science Question in Feminism as a Site of Discourse on the Privilege of Partial Perspective', *Feminist Studies*, **14(3)**, 575–599, (reprinted in Haraway, 1991).

——: 1991, *Simians, Cyborgs, and Women: The Reinvention of Nature*. NY: Routledge Press.

Harding, Sandra: 1990, 'Feminism, Science, and the Anti-Enlightenment Critiques', in *Feminism/Postmodernism*, ed. Linda J. Nicholson. NY: Routledge.

——: 1991, *Whose Science? Whose Knowledge?: Thinking from Women's Lives*. Ithaca: Cornell University Press.

—— (editor): 1993, *The "Racial" Economy of Science: Towards A Democratic Future*. Bloomington: Indiana University Press.

Hayles, N. Katherine: 1993, 'Constrained Constructivism: Locating Scientific Inquiry in the Theater of Representation', in *Realism and Representation: Essays on the Problem of Realism in Relation to Science, Literature, and Culture*, ed. by George Levin. Madison: The University of Wisconsin Press.

Honner, John: 1987, *The Description of Nature: Niels Bohr and the Philosophy of Quantum Physics*. Oxford: Clarendon Press.

Hooker, Clifford A.: 1972, 'The Nature of Quantum Mechanical Reality', in *Paradigms and Paradoxes*, ed. R. G. Colodny, Pittsburgh: U. of Pittsburgh Press.

Keller, Evelyn Fox: 1977, 'The Anomaly of a Woman in Physics', in *Working It Out*, ed. Ruddick and Daniels.

——: 1985, *Reflections on Gender and Science*. New Haven: Yale U. Press.

Kondo, Dorinne: 1989, *Crafting Selves: Power, Gender, and Discourses of Identity in a Japanese Workplace*. Chicago: Chicago Univ. Press.

Latour, Bruno: 1993, *We Have Never Been Modern*. Cambridge, MA: Harvard University Press.

Laudan, Larry: 1981, 'A Confutation of Convergent Realism', *Philosophy of Science*, **48**, 19–48.

Longino, Helen: 1990, *Science as Social Knowledge*. Princeton: Princeton Univ. Press.

Murdoch, Dugald: 1987, *Niels Bohr's Philosophy of Physics*. NY: Cambridge U. Press.

Pais, Abraham: 1982, *'Subtle is the Lord...': The Science and Life of Albert Einstein*. NY: Oxford Univ. Press.

Petersen, Aage: 1985, 'The Philosophy of Niels Bohr', in *Niels Bohr: A Centenary Volume*, ed. French, A. P., and Kennedy, P. J. Cambridge, MA: Harvard U. Press.

Pickering, Andrew: 1984, *Constructing Quarks: A Sociological History of Particle Physics*. Chicago: University of Chicago Press.

——: 1994, 'After Representation: Science Studies in the Performative Idiom'. Talk given at the Philosophy of Science Association Annual Meeting New Orleans, 14–16 October, 1994.

Rosenfeld, Leon (general ed.): 1972– , *Collected Works*. Amsterdam: North-Holland.

Sandoval, Cheyla: 1991, 'U.S. Third World Feminism: The Theory and Method of Oppositional Consciousness in the Postmodern World.' *Genders*, **10**.

Scully, Marlan O., Englert, Berthold-Georg, and Walther, Herbert: 1991, 'Quantum Opical Tests of Complementarity', *Nature*, **351**, 111–116.

Traweek, Sharon: 1988, *Beamtimes and Lifetimes: The World of High Energy Physicists*. Cambridge, MA: Harvard U. Press.

Winterson, Jeanette: 1992, *Written on the Body*. NY: Vintage Books.