Transgressing the Boundaries: Towards a Transformative Hermeneutics of Quantum Gravity

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> Transgressing disciplinary boundaries ... [is] a subversive undertaking since it is likely to violate the sanctuaries of accepted ways of perceiving. Among the most fortified boundaries have been those between the natural sciences and the humanities.
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> — *Valerie Greenberg, Transgressive Readings (1990, 1)*

> The struggle for the transformation of ideology into critical science ... proceeds on the foundation that the critique of all presuppositions of science and ideology must be the only absolute principle of science.
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> — *Stanley Aronowitz, Science as Power (1988b, 339)*

There are many natural scientists, and especially physicists, who continue to reject the notion that the disciplines concerned with social and cultural criticism can have anything to contribute, except perhaps peripherally, to their research. Still less are they receptive to the idea that the very foundations of their worldview must be revised or rebuilt in the light of such criticism. Rather, they cling to the dogma imposed by the long post-Enlightenment hegemony over the Western intellectual outlook, which can be summarized briefly as follows: that there exists an external world, whose properties are independent of any individual human being and indeed of humanity as a whole; that these properties are encoded in "eternal" physical laws; and that human beings can obtain reliable, albeit imperfect and tentative, knowledge of these laws by hewing to the "objective" procedures and epistemological strictures prescribed by the (so-called) scientific method.

But deep conceptual shifts within twentieth-century science have undermined this Cartesian-Newtonian metaphysics[1]; revisionist studies in the history and philosophy of science have cast further doubt on its credibility[2]; and, most recently, feminist and poststructuralist critiques have demystified the substantive content of mainstream Western scientific practice, revealing the ideology of domination concealed behind the façade of "objectivity".[3] It has thus become increasingly apparent that physical "reality", no less than social "reality", is at bottom a social and linguistic construct; that scientific "knowledge", far from being objective, reflects and encodes the dominant ideologies and power relations of the culture that produced it; that the truth claims of science are inherently theory-laden and self-referential; and consequently, that the discourse of the scientific community, for all its undeniable value, cannot assert a privileged epistemological status with respect to counter-hegemonic narratives emanating from dissident or marginalized communities. These themes can be traced, despite some differences of emphasis, in Aronowitz's analysis of the cultural fabric that produced quantum mechanics[4]; in

[1] Heisenberg (1958), Bohr (1963).

[2] Kuhn (1970), Feyerabend (1975), Latour (1987), Aronowitz (1988b), Bloor (1991).

[3] Merchant (1980), Keller (1985), Harding (1986,1991), Haraway (1989,1991), Best (1991).

[4] Aronowitz (1988b, especially chaps. 9 and 12).

Ross' discussion of oppositional discourses in post-quantum science[5]; in Irigaray's and Hayles' exegeses of gender encoding in fluid mechanics[6]; and in Harding's comprehensive critique of the gender ideology underlying the natural sciences in general and physics in particular.[7]

Here my aim is to carry these deep analyses one step farther, by taking account of recent developments in quantum gravity: the emerging branch of physics in which Heisenberg's quantum mechanics and Einstein's general relativity are at once synthesized and superseded. In quantum gravity, as we shall see, the spacetime manifold ceases to exist as an objective physical reality; geometry becomes relational and contextual; and the foundational conceptual categories of prior science — among them, existence itself — become problematized and relativized. This conceptual revolution, I will argue, has profound implications for the content of a future postmodern and liberatory science.

My approach will be as follows: First I will review very briefly some of the philosophical and ideological issues raised by quantum mechanics and by classical general relativity. Next I will sketch the outlines of the emerging theory of quantum gravity, and discuss some of the conceptual issues it raises. Finally, I will comment on the cultural and political implications of these scientific developments. It should be emphasized that this article is of necessity tentative and preliminary; I do not pretend to answer all of the questions that I raise. My aim is, rather, to draw the attention of readers to these important developments in physical science, and to sketch as best I can their philosophical and political implications. I have endeavored here to keep mathematics to a bare minimum; but I have taken care to provide references where interested readers can find all requisite details.

Quantum Mechanics: Uncertainty, Complementarity, Discontinuity and Interconnectedness

It is not my intention to enter here into the extensive debate on the conceptual foundations of quantum mechanics.[8] Suffice it to say that anyone who has seriously studied the equations of quantum mechanics will assent to Heisenberg's measured (pardon the pun) summary of his celebrated *uncertainty principle*:

> We can no longer speak of the behaviour of the particle independently of the process of observation. As a final consequence, the natural laws formulated mathematically in quantum theory no longer deal with the elementary particles themselves but with our knowledge of them. Nor is it any longer possible to ask whether or not these particles exist in space and time objectively ...

[5] Ross (1991, introduction and chap. 1).

[6] Irigaray (1985), Hayles (1992).

[7] Harding (1986, especially chaps. 2 and 10); Harding (1991, especially chap. 4).

[8] For a sampling of views, see Jammer (1974), Bell (1987), Albert (1992), Dürr, Goldstein and Zanghí (1992), Weinberg (1992, chap. IV), Coleman (1993), Maudlin (1994), Bricmont (1994).

> When we speak of the picture of nature in the exact science of our age, we do not mean a picture of nature so much as a *picture of our relationships with nature*. ... Science no longer confronts nature as an objective observer, but sees itself as an actor in this interplay between man [*sic*] and nature. The scientific method of analysing, explaining and classifying has become conscious of its limitations, which arise out of the fact that by its intervention science alters and refashions the object of investigation. In other words, method and object can no longer be separated.[9,10]

Along the same lines, Niels Bohr wrote:

> An independent reality in the ordinary physical sense can ... neither be ascribed to the phenomena nor to the agencies of observation.[11]

Stanley Aronowitz has convincingly traced this worldview to the crisis of liberal hegemony in Central Europe in the years prior and subsequent to World War I.[12,13]

A second important aspect of quantum mechanics is its principle of *complementarity* or *dialecticism*. Is light a particle or a wave? Complementarity "is the realization that particle and wave behavior are mutually exclusive, yet that both are necessary for a complete description of all phenomena."[14] More generally, notes

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[9]Heisenberg (1958, 15, 28–29), emphasis in Heisenberg's original. See also Overstreet (1980), Craige (1982), Hayles (1984), Greenberg (1990), Booker (1990) and Porter (1990) for examples of cross-fertilization of ideas between relativistic quantum theory and literary criticism.

[10]Unfortunately, Heisenberg's uncertainty principle has frequently been misinterpreted by amateur philosophers. As Gilles Deleuze and Félix Guattari (1994, 129–130) lucidly point out,

> in quantum physics, Heisenberg's demon does not express the impossibility of measuring both the speed and the position of a particle on the grounds of a subjective interference of the measure with the measured, but it measures exactly an objective state of affairs that leaves the respective position of two of its particles outside of the field of its actualization, the number of independent variables being reduced and the values of the coordinates having the same probability. ... Perspectivism, or scientific relativism, is never relative to a subject: it constitutes not a relativity of truth but, on the contrary, a truth of the relative, that is to say, of variables whose cases it orders according to the values it extracts from them in its system of coordinates ...

[11]Bohr (1928), cited in Pais (1991, 314).

[12]Aronowitz (1988b, 251–256).

[13]See also Porush (1989) for a fascinating account of how a second group of scientists and engineers — cyberneticists — contrived, with considerable success, to subvert the most revolutionary implications of quantum physics. The main limitation of Porush's critique is that it remains solely on a cultural and philosophical plane; his conclusions would be immeasurably strengthened by an analysis of economic and political factors. (For example, Porush fails to mention that engineer-cyberneticist Claude Shannon worked for the then-telephone monopoly AT&T.) A careful analysis would show, I think, that the victory of cybernetics over quantum physics in the 1940's and 50's can be explained in large part by the centrality of cybernetics to the ongoing capitalist drive for automation of industrial production, compared to the marginal industrial relevance of quantum mechanics.

[14]Pais (1991, 23). Aronowitz (1981, 28) has noted that wave-particle duality renders the "will to totality in modern science" severely problematic:

Heisenberg,

> the different intuitive pictures which we use to describe atomic systems, although fully adequate for given experiments, are nevertheless mutually exclusive. Thus, for instance, the Bohr atom can be described as a small-scale planetary system, having a central atomic nucleus about which the external electrons revolve. For other experiments, however, it might be more convenient to imagine that the atomic nucleus is surrounded by a system of stationary waves whose frequency is characteristic of the radiation emanating from the atom. Finally, we can consider the atom chemically. ... Each picture is legitimate when used in the right place, but the different pictures are contradictory and therefore we call them mutually complementary.[15]

And once again Bohr:

> A complete elucidation of one and the same object may require diverse points of view which defy a unique description. Indeed, strictly speaking, the conscious analysis of any concept stands in a relation of exclusion to its immediate application.[16]

This foreshadowing of postmodernist epistemology is by no means coincidental. The profound connections between complementarity and deconstruction have recently

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> The differences within physics between wave and particle theories of matter, the indeterminacy principle discovered by Heisenberg, Einstein's relativity theory, all are accommodations to the impossibility of arriving at a unified field theory, one in which the "anomaly" of difference for a theory which posits identity may be resolved without challenging the presuppositions of science itself.

For further development of these ideas, see Aronowitz (1988a, 524–525, 533).

[15] Heisenberg (1958, 40–41).

[16] Bohr (1934), cited in Jammer (1974, 102). Bohr's analysis of the complementarity principle also led him to a social outlook which was, for its time and place, notably progressive. Consider the following excerpt from a 1938 lecture (Bohr 1958, 30):

> I may perhaps here remind you of the extent to which in certain societies the roles of men and women are reversed, not only regarding domestic and social duties but also regarding behaviour and mentality. Even if many of us, in such a situation, might perhaps at first shrink from admitting the possibility that it is entirely a caprice of fate that the people concerned have their specific culture and not ours, and we not theirs instead of our own, it is clear that even the slightest suspicion in this respect implies a betrayal of the national complacency inherent in any human culture resting in itself.

been elucidated by Froula[17] and Honner[18], and, in great depth, by Plotnitsky.[19,20,21]

A third aspect of quantum physics is *discontinuity* or *rupture*: as Bohr explained,

> [the] essence [of the quantum theory] may be expressed in the so-called quantum postulate, which attributes to any atomic process an essential discontinuity, or rather individuality, completely foreign to the classical theories and symbolized by Planck's quantum of action.[22]

A half-century later, the expression "quantum leap" has so entered our everyday vocabulary that we are likely to use it without any consciousness of its origins in physical theory.

Finally, Bell's theorem[23] and its recent generalizations[24] show that an act of observation here and now can affect not only the object being observed — as Heisenberg told us — but also an object *arbitrarily far away* (say, on Andromeda galaxy). This phenomenon — which Einstein termed "spooky" — imposes a radical reeval-

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[17] Froula (1985).

[18] Honner (1994).

[19] Plotnitsky (1994). This impressive work also explains the intimate connections with Gödel's proof of the incompleteness of formal systems and with Skolem's construction of nonstandard models of arithmetic, as well as with Bataille's general economy. For further discussion of Bataille's physics, see Hochroth (1995).

[20] Numerous other examples could be adduced. For instance, Barbara Johnson (1989, 12) makes no specific reference to quantum physics; but her description of deconstruction is an eerily exact summary of the complementarity principle:

> Instead of a simple "either/or" structure, deconstruction attempts to elaborate a discourse that says *neither* "either/or", *nor* "both/and" nor even "neither/nor", while at the same time not totally abandoning these logics either.

See also McCarthy (1992) for a thought-provoking analysis that raises disturbing questions about the "complicity" between (nonrelativistic) quantum physics and deconstruction.

[21] Permit me in this regard a personal recollection: Fifteen years ago, when I was a graduate student, my research in relativistic quantum field theory led me to an approach which I called "de[con]structive quantum field theory" (Sokal 1982). Of course, at that time I was completely ignorant of Jacques Derrida's work on deconstruction in philosophy and literary theory. In retrospect, however, there is a striking affinity: my work can be read as an exploration of how the orthodox discourse (e.g. Itzykson and Zuber 1980) on scalar quantum field theory in four-dimensional spacetime (in technical terms, "renormalized perturbation theory" for the φ^4_4 theory) can be seen to assert its own unreliability and thereby to undermine its own affirmations. Since then, my work has shifted to other questions, mostly connected with phase transitions; but subtle homologies between the two fields can be discerned, notably the theme of discontinuity (see Notes 22 and 81 below). For further examples of deconstruction in quantum field theory, see Merz and Knorr Cetina (1994).

[22] Bohr (1928), cited in Jammer (1974, 90).

[23] Bell (1987, especially chaps. 10 and 16). See also Maudlin (1994, chap. 1) for a clear account presupposing no specialized knowledge beyond high-school algebra.

[24] Greenberger *et al.* (1989,1990), Mermin (1990,1993).

uation of the traditional mechanistic concepts of space, object and causality[25], and suggests an alternative worldview in which the universe is characterized by interconnectedness and (w)holism: what physicist David Bohm has called "implicate order".[26] New Age interpretations of these insights from quantum physics have often gone overboard in unwarranted speculation, but the general soundness of the argument is undeniable.[27] In Bohr's words, "Planck's discovery of the *elementary quantum of action* ... revealed a feature of *wholeness* inherent in atomic physics, going far beyond the ancient idea of the limited divisibility of matter."[28]

Hermeneutics of Classical General Relativity

In the Newtonian mechanistic worldview, space and time are distinct and absolute.[29] In Einstein's special theory of relativity (1905), the distinction between space and

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[25] Aronowitz (1988b, 331) has made a provocative observation concerning nonlinear causality in quantum mechanics and its relation to the social construction of time:

> Linear causality assumes that the relation of cause and effect can be expressed as a function of temporal succession. Owing to recent developments in quantum mechanics, we can postulate that it is possible to know the effects of absent causes; that is, speaking metaphorically, effects may anticipate causes so that our perception of them may precede the physical occurrence of a "cause." The hypothesis that challenges our conventional conception of linear time and causality and that asserts the possibility of time's reversal also raises the question of the degree to which the concept of "time's arrow" is inherent in all scientific theory. If these experiments are successful, the conclusions about the way time as "clock-time" has been constituted historically will be open to question. We will have "proved" by means of experiment what has long been suspected by philosophers, literary and social critics: that time is, in part, a conventional construction, its segmentation into hours and minutes a product of the need for industrial discipline, for rational organization of social labor in the early bourgeois epoch.

The theoretical analyses of Greenberger *et al.* (1989,1990) and Mermin (1990,1993) provide a striking example of this phenomenon; see Maudlin (1994) for a detailed analysis of the implications for concepts of causality and temporality. An experimental test, extending the work of Aspect *et al.* (1982), will likely be forthcoming within the next few years.

[26] Bohm (1980). The intimate relations between quantum mechanics and the mind-body problem are discussed in Goldstein (1983, chaps. 7 and 8).

[27] Among the voluminous literature, the book by Capra (1975) can be recommended for its scientific accuracy and its accessibility to non-specialists. In addition, the book by Sheldrake (1981), while occasionally speculative, is in general sound. For a sympathetic but critical analysis of New Age theories, see Ross (1991, chap. 1). For a critique of Capra's work from a Third World perspective, see Alvares (1992, chap. 6).

[28] Bohr (1963, 2), emphasis in Bohr's original.

[29] Newtonian atomism treats particles as hyperseparated in space and time, backgrounding their interconnectedness (Plumwood 1993a, 125); indeed, "the only 'force' allowed within the mechanistic framework is that of kinetic energy — the energy of motion by contact — all other purported forces, including action at a distance, being regarded as occult" (Mathews 1991, 17). For critical analyses of the Newtonian mechanistic worldview, see Weil (1968, especially chap. 1), Merchant (1980), Berman (1981), Keller (1985, chaps. 2 and 3), Mathews (1991, chap. 1) and Plumwood (1993a, chap. 5).

time dissolves: there is only a new unity, four-dimensional space-time, and the observer's perception of "space" and "time" depends on her state of motion.[30] In Hermann Minkowski's famous words (1908):

> Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality.[31]

Nevertheless, the underlying geometry of Minkowskian space-time remains absolute.[32]

It is in Einstein's general theory of relativity (1915) that the radical conceptual break occurs: the space-time geometry becomes contingent and dynamical, encoding in itself the gravitational field. Mathematically, Einstein breaks with the tradition dating back to Euclid (and which is inflicted on high-school students even today!), and employs instead the non-Euclidean geometry developed by Riemann. Einstein's equations are highly nonlinear, which is why traditionally-trained mathematicians find them so difficult to solve.[33] Newton's gravitational theory corresponds to the

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[30] According to the traditional textbook account, special relativity is concerned with the coordinate transformations relating *two* frames of reference in uniform relative motion. But this is a misleading oversimplification, as Latour (1988) has pointed out:

> How can one decide whether an observation made in a train about the behaviour of a falling stone can be made to coincide with the observation made of the same falling stone from the embankment? If there are only one, or even *two*, frames of reference, no solution can be found since the man in the train claims he observes a straight line and the man on the embankment a parabola. ... Einstein's solution is to consider *three* actors: one in the train, one on the embankment and a third one, the author [enunciator] or one of its representants, who tries to superimpose the coded observations sent back by the two others. ... [W]ithout the enunciator's position (hidden in Einstein's account), and without the notion of centres of calculation, Einstein's own technical argument is ununderstandable ... [pp. 10–11 and 35, emphasis in original]

In the end, as Latour wittily but accurately observes, special relativity boils down to the proposition that

> more frames of reference with less privilege can be accessed, reduced, accumulated and combined, observers can be delegated to a few more places in the infinitely large (the cosmos) and the infinitely small (electrons), and the readings they send will be understandable. His [Einstein's] book could well be titled: 'New Instructions for Bringing Back Long-Distance Scientific Travellers'. [pp. 22–23]

Latour's critical analysis of Einstein's logic provides an eminently accessible introduction to special relativity for non-scientists.

[31] Minkowski (1908), translated in Lorentz *et al.* (1952, 75).

[32] It goes without saying that special relativity proposes new concepts not only of space and time but also of mechanics. In special relativity, as Virilio (1991, 136) has noted, "the dromospheric space, space-speed, is physically described by what is called the 'logistic equation,' the result of the product of the mass displaced by the speed of its displacement, MxV." This radical alteration of the Newtonian formula has profound consequences, particularly in the quantum theory; see Lorentz *et al.* (1952) and Weinberg (1992) for further discussion.

[33] Steven Best (1991, 225) has put his finger on the crux of the difficulty, which is that "unlike the linear equations used in Newtonian and even quantum mechanics, non-linear equations do [not]

crude (and conceptually misleading) truncation of Einstein's equations in which the nonlinearity is simply ignored. Einstein's general relativity therefore subsumes all the putative successes of Newton's theory, while going beyond Newton to predict radically new phenomena that arise directly from the nonlinearity: the bending of starlight by the sun, the precession of the perihelion of Mercury, and the gravitational collapse of stars into black holes.

General relativity is so weird that some of its consequences — deduced by impeccable mathematics, and increasingly confirmed by astrophysical observation — read like science fiction. Black holes are by now well known, and wormholes are beginning to make the charts. Perhaps less familiar is Gödel's construction of an Einstein space-time admitting closed timelike curves: that is, a universe in which it is possible to travel *into one's own past*![34]

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have the simple additive property whereby chains of solutions can be constructed out of simple, independent parts". For this reason, the strategies of atomization, reductionism and context-stripping that underlie the Newtonian scientific methodology simply do not work in general relativity.

[34]Gödel (1949). For a summary of recent work in this area, see 't Hooft (1993).

Thus, general relativity forces upon us radically new and counterintuitive notions of space, time and causality[35,36,37,38]; so it is not surprising that it has had a profound impact not only on the natural sciences but also on philosophy, literary criticism, and the human sciences. For example, in a celebrated symposium three decades ago on *Les Langages Critiques et les Sciences de l'Homme*, Jean Hyppolite raised an incisive question about Jacques Derrida's theory of structure and sign in scientific discourse:

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[35]These new notions of space, time and causality are *in part* foreshadowed already in special relativity. Thus, Alexander Argyros (1991, 137) has noted that

> in a universe dominated by photons, gravitons, and neutrinos, that is, in the very early universe, the theory of special relativity suggests that any distinction between before and after is impossible. For a particle traveling at the speed of light, or one traversing a distance that is in the order of the Planck length, all events are simultaneous.

However, I cannot agree with Argyros' conclusion that Derridean deconstruction is therefore inapplicable to the hermeneutics of early-universe cosmology: Argyros' argument to this effect is based on an impermissibly totalizing use of special relativity (in technical terms, "light-cone coordinates") in a context where *general* relativity is inescapable. (For a similar but less innocent error, see Note 40 below.)

[36]Jean-François Lyotard (1989, 5–6) has pointed out that not only general relativity, but also modern elementary-particle physics, imposes new notions of time:

> In contemporary physics and astrophysics ... a particle has a sort of elementary memory and consequently a temporal filter. This is why contemporary physicists tend to think that time emanates from matter itself, and that it is not an entity outside or inside the universe whose function it would be to gather all different times into universal history. It is only in certain regions that such — only partial — syntheses could be detected. There would on this view be areas of determinism where complexity is increasing.

Furthermore, Michel Serres (1992, 89–91) has noted that chaos theory (Gleick 1987) and percolation theory (Stauffer 1985) have contested the traditional linear concept of time:

> Time does not always flow along a line ... or a plane, but along an extraordinarily complex manifold, as if it showed stopping points, ruptures, sinks [*puits*], funnels of overwhelming acceleration [*cheminées d'accélération foudroyante*], rips, lacunae, all sown randomly ... Time flows in a turbulent and chaotic manner; it percolates. [Translation mine. Note that in the theory of dynamical systems, "*puits*" is a technical term meaning "sink", i.e. the opposite of "source".]

These multiple insights into the nature of time, provided by different branches of physics, are a further illustration of the complementarity principle.

[37]General relativity can arguably be read as corroborating the Nietzschean deconstruction of causality (see e.g. Culler 1982, 86–88), although some relativists find this interpretation problematic. In quantum mechanics, by contrast, this phenomenon is rather firmly established (see Note 25 above).

[38]General relativity is also, of course, the starting point for contemporary astrophysics and physical cosmology. See Mathews (1991, 59–90, 109–116, 142–163) for a detailed analysis of the connections between general relativity (and its generalizations called "geometrodynamics") and an ecological worldview. For an astrophysicist's speculations along similar lines, see Primack and Abrams (1995).

> When I take, for example, the structure of certain algebraic constructions [ensembles], where is the center? Is the center the knowledge of general rules which, after a fashion, allow us to understand the interplay of the elements? Or is the center certain elements which enjoy a particular privilege within the ensemble? ... With Einstein, for example, we see the end of a kind of privilege of empiric evidence. And in that connection we see a constant appear, a constant which is a combination of space-time, which does not belong to any of the experimenters who live the experience, but which, in a way, dominates the whole construct; and this notion of the constant — is this the center?[39]

Derrida's perceptive reply went to the heart of classical general relativity:

> The Einsteinian constant is not a constant, is not a center. It is the very concept of variability — it is, finally, the concept of the game. In other words, it is not the concept of some*thing* — of a center starting from which an observer could master the field — but the very concept of the game ...[40]

In mathematical terms, Derrida's observation relates to the invariance of the Einstein field equation $G_{\mu\nu} = 8\pi G T_{\mu\nu}$ under nonlinear space-time diffeomorphisms (self-mappings of the space-time manifold which are infinitely differentiable but not necessarily analytic). The key point is that this invariance group "acts transitively": this means that any space-time point, if it exists at all, can be transformed into any other. In this way the infinite-dimensional invariance group erodes the distinction between observer and observed; the π of Euclid and the G of Newton, formerly thought to be constant and universal, are now perceived in their ineluctable historicity; and the putative observer becomes fatally de-centered, disconnected from any epistemic link to a space-time point that can no longer be defined by geometry alone.

Quantum Gravity: String, Weave or Morphogenetic Field?

However, this interpretation, while adequate within classical general relativity, becomes incomplete within the emerging postmodern view of quantum gravity. When even the gravitational field — geometry incarnate — becomes a noncommuting (and hence nonlinear) operator, how can the classical interpretation of $G_{\mu\nu}$ as a geometric entity be sustained? Now not only the observer, but the very concept of geometry, becomes relational and contextual.

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[39] Discussion to Derrida (1970, 265–266).

[40] Derrida (1970, 267). Right-wing critics Gross and Levitt (1994, 79) have ridiculed this statement, willfully misinterpreting it as an assertion about *special* relativity, in which the Einsteinian constant c (the speed of light in vacuum) is of course constant. No reader conversant with modern physics — except an ideologically biased one — could fail to understand Derrida's unequivocal reference to *general* relativity.

The synthesis of quantum theory and general relativity is thus the central unsolved problem of theoretical physics[41]; no one today can predict with confidence what will be the language and ontology, much less the content, of this synthesis, when and if it comes. It is, nevertheless, useful to examine historically the metaphors and imagery that theoretical physicists have employed in their attempts to understand quantum gravity.

The earliest attempts — dating back to the early 1960's — to visualize geometry on the Planck scale (about 10^{-33} centimeters) portrayed it as "space-time foam": bubbles of space-time curvature, sharing a complex and ever-changing topology of interconnections.[42] But physicists were unable to carry this approach farther, perhaps due to the inadequate development at that time of topology and manifold theory (see below).

In the 1970's physicists tried an even more conventional approach: simplify the Einstein equations by pretending that they are *almost linear*, and then apply the standard methods of quantum field theory to the thus-oversimplified equations. But this method, too, failed: it turned out that Einstein's general relativity is, in technical language, "perturbatively nonrenormalizable".[43] This means that the strong nonlinearities of Einstein's general relativity are intrinsic to the theory; any attempt to pretend that the nonlinearities are weak is simply self-contradictory. (This is not surprising: the almost-linear approach destroys the most characteristic features of general relativity, such as black holes.)

In the 1980's a very different approach, known as string theory, became popular: here the fundamental constituents of matter are not point-like particles but rather tiny (Planck-scale) closed and open strings.[44] In this theory, the space-time manifold does not exist as an objective physical reality; rather, space-time is a derived concept, an approximation valid only on large length scales (where "large" means "much larger than 10^{-33} centimeters"!). For a while many enthusiasts of string theory thought they were closing in on a Theory of Everything — modesty is not

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[41] Luce Irigaray (1987, 77–78) has pointed out that the contradictions between quantum theory and field theory are in fact the culmination of a historical process that began with Newtonian mechanics:

> The Newtonian break has ushered scientific enterprise into a world where sense perception is worth little, a world which can lead to the annihilation of the very stakes of physics' object: the matter (whatever the predicates) of the universe and of the bodies that constitute it. In this very science, moreover [*d'ailleurs*], cleavages exist: quantum theory/field theory, mechanics of solids/dynamics of fluids, for example. But the imperceptibility of the matter under study often brings with it the paradoxical privilege of *solidity* in discoveries and a delay, even an abandoning of the analysis of the infinity [*l'in-fini*] of the fields of force.

I have here corrected the translation of "*d'ailleurs*", which means "moreover" or "besides" (not "however").

[42] Wheeler (1964).

[43] Isham (1991, sec. 3.1.4).

[44] Green, Schwarz and Witten (1987).

one of their virtues — and some still think so. But the mathematical difficulties in string theory are formidable, and it is far from clear that they will be resolved any time soon.

More recently, a small group of physicists has returned to the full nonlinearities of Einstein's general relativity, and — using a new mathematical symbolism invented by Abhay Ashtekar — they have attempted to visualize the structure of the corresponding quantum theory.[45] The picture they obtain is intriguing: As in string theory, the space-time manifold is only an approximation valid at large distances, not an objective reality. At small (Planck-scale) distances, the geometry of space-time is a *weave*: a complex interconnection of threads.

Finally, an exciting proposal has been taking shape over the past few years in the hands of an interdisciplinary collaboration of mathematicians, astrophysicists and biologists: this is the theory of the morphogenetic field.[46] Since the mid-1980's evidence has been accumulating that this field, first conceptualized by developmental biologists[47], is in fact closely linked to the quantum *gravitational* field[48]: (a) it pervades all space; (b) it interacts with all matter and energy, irrespective of whether or not that matter/energy is magnetically charged; and, most significantly, (c) it is what is known mathematically as a "symmetric second-rank tensor". All three properties are characteristic of gravity; and it was proven some years ago that the only self-consistent *nonlinear* theory of a symmetric second-rank tensor field is, at least at low energies, precisely Einstein's general relativity.[49] Thus, if the evidence for (a), (b) and (c) holds up, we can infer that the morphogenetic field is the quantum counterpart of Einstein's gravitational field. Until recently this theory has been ignored or even scorned by the high-energy-physics establishment, who have traditionally resented the encroachment of biologists (not to mention humanists) on their "turf".[50] However, some theoretical physicists have recently begun to give this theory a second look, and there are good prospects for progress in the near future.[51]

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[45] Ashtekar, Rovelli and Smolin (1992), Smolin (1992).

[46] Sheldrake (1981,1991), Briggs and Peat (1984, chap. 4), Granero-Porati and Porati (1984), Kazarinoff (1985), Schiffmann (1989), Psarev (1990), Brooks and Castor (1990), Heinonen, Kilpeläinen and Martio (1992), Rensing (1993). For an in-depth treatment of the mathematical background to this theory, see Thom (1975,1990); and for a brief but insightful analysis of the philosophical underpinnings of this and related approaches, see Ross (1991, 40–42, 253n).

[47] Waddington (1965), Corner (1966), Gierer *et al.* (1978).

[48] Some early workers thought that the morphogenetic field might be related to the electromagnetic field, but it is now understood that this is merely a suggestive analogy: see Sheldrake (1981, 77, 90) for a clear exposition. Note also point (b) below.

[49] Boulware and Deser (1975).

[50] For another example of the "turf" effect, see Chomsky (1979, 6–7).

[51] To be fair to the high-energy-physics establishment, I should mention that there is also an honest intellectual reason for their opposition to this theory: inasmuch as it posits a subquantum interaction linking patterns throughout the universe, it is, in physicists' terminology, a "non-local

It is still too soon to say whether string theory, the space-time weave or morphogenetic fields will be confirmed in the laboratory: the experiments are not easy to perform. But it is intriguing that all three theories have similar conceptual characteristics: strong nonlinearity, subjective space-time, inexorable flux, and a stress on the topology of interconnectedness.

Differential Topology and Homology

Unbeknownst to most outsiders, theoretical physics underwent a significant transformation — albeit not yet a true Kuhnian paradigm shift — in the 1970's and 80's: the traditional tools of mathematical physics (real and complex analysis), which deal with the space-time manifold only locally, were supplemented by topological approaches (more precisely, methods from differential topology[52]) that account for the global (holistic) structure of the universe. This trend was seen in the analysis of anomalies in gauge theories[53]; in the theory of vortex-mediated phase transitions[54]; and in string and superstring theories.[55] Numerous books and review articles on "topology for physicists" were published during these years.[56]

At about the same time, in the social and psychological sciences Jacques Lacan pointed out the key role played by differential topology:

> This diagram [the Möbius strip] can be considered the basis of a sort of essential inscription at the origin, in the knot which constitutes the subject. This goes much further than you may think at first, because you can search for the sort of surface able to receive such inscriptions. You can perhaps see that the sphere,

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field theory". Now, the history of classical theoretical physics since the early 1800's, from Maxwell's electrodynamics to Einstein's general relativity, can be read in a very deep sense as a trend away from action-at-a-distance theories and towards *local field theories*: in technical terms, theories expressible by partial differential equations (Einstein and Infeld 1961, Hayles 1984). So a non-local field theory definitely goes against the grain. On the other hand, as Bell (1987) and others have convincingly argued, the key property of quantum mechanics is precisely its *non-locality*, as expressed in Bell's theorem and its generalizations (see Notes 23 and 24 above). Therefore, a non-local field theory, although jarring to physicists' classical intuition, is not only natural but in fact *preferred* (and possibly even *mandatory*?) in the quantum context. This is why classical general relativity is a local field theory, while quantum gravity (whether string, weave or morphogenetic field) is inherently non-local.

[52]Differential topology is the branch of mathematics concerned with those properties of surfaces (and higher-dimensional manifolds) that are unaffected by smooth deformations. The properties it studies are therefore primarily qualitative rather than quantitative, and its methods are holistic rather than Cartesian.

[53]Alvarez-Gaumé (1985). The alert reader will notice that anomalies in "normal science" are the usual harbinger of a *future* paradigm shift (Kuhn 1970).

[54]Kosterlitz and Thouless (1973). The flowering of the theory of phase transitions in the 1970's probably reflects an increased emphasis on discontinuity and rupture in the wider culture: see Note 81 below.

[55]Green, Schwarz and Witten (1987).

[56]A typical such book is Nash and Sen (1983).

> that old symbol for totality, is unsuitable. A torus, a Klein bottle, a cross-cut surface, are able to receive such a cut. And this diversity is very important as it explains many things about the structure of mental disease. If one can symbolize the subject by this fundamental cut, in the same way one can show that a cut on a torus corresponds to the neurotic subject, and on a cross-cut surface to another sort of mental disease.[57,58]

As Althusser rightly commented, "Lacan finally gives Freud's thinking the scientific concepts that it requires".[59] More recently, Lacan's *topologie du sujet* has been applied fruitfully to cinema criticism[60] and to the psychoanalysis of AIDS.[61] In mathematical terms, Lacan is here pointing out that the first homology group[62] of the sphere is trivial, while those of the other surfaces are profound; and this homology is linked with the connectedness or disconnectedness of the surface after one or more cuts.[63] Furthermore, as Lacan suspected, there is an intimate connection between the external structure of the physical world and its inner psychological representation *qua* knot theory: this hypothesis has recently been confirmed by Witten's derivation of knot invariants (in particular the Jones polynomial[64]) from

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[57]Lacan (1970, 192–193), lecture given in 1966. For an in-depth analysis of Lacan's use of ideas from mathematical topology, see Juranville (1984, chap. VII), Granon-Lafont (1985,1990), Vappereau (1985) and Nasio (1987,1992); a brief summary is given by Leupin (1991). See Hayles (1990, 80) for an intriguing connection between Lacanian topology and chaos theory; unfortunately she does not pursue it. See also Žižek (1991, 38–39, 45–47) for some further homologies between Lacanian theory and contemporary physics. Lacan also made extensive use of concepts from set-theoretic number theory: see e.g. Miller (1977/78) and Ragland-Sullivan (1990).

[58]In bourgeois social psychology, topological ideas had been employed by Kurt Lewin as early as the 1930's, but this work foundered for two reasons: first, because of its individualist ideological preconceptions; and second, because it relied on old-fashioned point-set topology rather than modern differential topology and catastrophe theory. Regarding the second point, see Back (1992).

[59]Althusser (1993, 50): "Il suffit, à cette fin, reconnaître que Lacan confère enfin à la pensée de Freud, les concepts scientifiques qu'elle exige". This famous essay on "Freud and Lacan" was first published in 1964, before Lacan's work had reached its highest level of mathematical rigor. It was reprinted in English translation in 1969 (*New Left Review*).

[60]Miller (1977/78, especially pp. 24–25). This article has become quite influential in film theory: see e.g. Jameson (1982, 27–28) and the references cited there. As Strathausen (1994, 69) indicates, Miller's article is tough going for the reader not well versed in the mathematics of set theory. But it is well worth the effort. For a gentle introduction to set theory, see Bourbaki (1970).

[61]Dean (1993, especially pp. 107–108).

[62]Homology theory is one of the two main branches of the mathematical field called *algebraic topology*. For an excellent introduction to homology theory, see Munkres (1984); or for a more popular account, see Eilenberg and Steenrod (1952). A fully relativistic homology theory is discussed e.g. in Eilenberg and Moore (1965). For a dialectical approach to homology theory and its dual, cohomology theory, see Massey (1978). For a cybernetic approach to homology, see Saludes i Closa (1984).

[63]For the relation of homology to cuts, see Hirsch (1976, 205–208); and for an application to collective movements in quantum field theory, see Caracciolo *et al.* (1993, especially app. A.1).

[64]Jones (1985).

three-dimensional Chern-Simons quantum field theory.[65]

Analogous topological structures arise in quantum gravity, but inasmuch as the manifolds involved are multidimensional rather than two-dimensional, higher homology groups play a role as well. These multidimensional manifolds are no longer amenable to visualization in conventional three-dimensional Cartesian space: for example, the projective space RP^3, which arises from the ordinary 3-sphere by identification of antipodes, would require a Euclidean embedding space of dimension at least 5.[66] Nevertheless, the higher homology groups can be perceived, at least approximately, via a suitable multidimensional (nonlinear) logic.[67,68]

Manifold Theory: (W)holes and Boundaries

Luce Irigaray, in her famous article "Is the Subject of Science Sexed?", pointed out that

> the mathematical sciences, in the theory of wholes [*théorie des ensembles*], concern themselves with closed and open spaces ... They concern themselves very little with the question of the partially open, with wholes that are not clearly delineated [*ensembles flous*], with any analysis of the problem of borders [*bords*] ...[69]

In 1982, when Irigaray's essay first appeared, this was an incisive criticism: differential topology has traditionally privileged the study of what are known technically as "manifolds without boundary". However, in the past decade, under the impetus of the feminist critique, some mathematicians have given renewed attention to the theory of "manifolds with boundary" [Fr. *variétés à bord*].[70] Perhaps not coinciden-

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[65] Witten (1989).

[66] James (1971, 271–272). It is, however, worth noting that the space RP^3 is homeomorphic to the group $SO(3)$ of rotational symmetries of conventional three-dimensional Euclidean space. Thus, some aspects of three-dimensional Euclidicity are preserved (albeit in modified form) in the postmodern physics, just as some aspects of Newtonian mechanics were preserved in modified form in Einsteinian physics.

[67] Kosko (1993). See also Johnson (1977, 481–482) for an analysis of Derrida's and Lacan's efforts toward transcending the Euclidean spatial logic.

[68] Along related lines, Eve Seguin (1994, 61) has noted that "logic says nothing about the world and attributes to the world properties that are but constructs of theoretical thought. This explains why physics since Einstein has relied on alternative logics, such as trivalent logic which rejects the principle of the excluded middle." A pioneering (and unjustly forgotten) work in this direction, likewise inspired by quantum mechanics, is Lupasco (1951). See also Plumwood (1993b, 453–459) for a specifically feminist perspective on nonclassical logics. For a critical analysis of one nonclassical logic ("boundary logic") and its relation to the ideology of cyberspace, see Markley (1994).

[69] Irigaray (1987, 76–77), essay originally appeared in French in 1982. Irigaray's phrase "*théorie des ensembles*" can also be rendered as "theory of sets", and "*bords*" is usually translated in the mathematical context as "boundaries". Her phrase "*ensembles flous*" may refer to the new mathematical field of "fuzzy sets" (Kaufmann 1973, Kosko 1993).

[70] See e.g. Hamza (1990), McAvity and Osborn (1991), Alexander, Berg and Bishop (1993) and the references cited therein.

tally, it is precisely these manifolds that arise in the new physics of conformal field theory, superstring theory and quantum gravity.

In string theory, the quantum-mechanical amplitude for the interaction of n closed or open strings is represented by a functional integral (basically, a sum) over fields living on a two-dimensional manifold with boundary.[71] In quantum gravity, we may expect that a similar representation will hold, except that the two-dimensional manifold with boundary will be replaced by a multidimensional one. Unfortunately, multidimensionality goes against the grain of conventional linear mathematical thought, and despite a recent broadening of attitudes (notably associated with the study of multidimensional nonlinear phenomena in chaos theory), the theory of multidimensional manifolds with boundary remains somewhat underdeveloped. Nevertheless, physicists' work on the functional-integral approach to quantum gravity continues apace[72], and this work is likely to stimulate the attention of mathematicians.[73]

As Irigaray anticipated, an important question in all of these theories is: Can the boundary be transgressed (crossed), and if so, what happens then? Technically this is known as the problem of "boundary conditions". At a purely mathematical level, the most salient aspect of boundary conditions is the great diversity of possibilities: for example, "free b.c." (no obstacle to crossing), "reflecting b.c." (specular reflection as in a mirror), "periodic b.c." (re-entrance in another part of the manifold), and "antiperiodic b.c." (re-entrance with 180° twist). The question posed by physicists is: Of all these conceivable boundary conditions, which ones actually occur in the representation of quantum gravity? Or perhaps, do *all* of them occur simultaneously and on an equal footing, as suggested by the complementarity principle?[74]

At this point my summary of developments in physics must stop, for the simple reason that the answers to these questions — if indeed they have univocal answers — are not yet known. In the remainder of this essay, I propose to take as my starting point those features of the theory of quantum gravity which *are* relatively well established (at least by the standards of conventional science), and attempt to draw out their philosophical and political implications.

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[71] Green, Schwarz and Witten (1987).

[72] Hamber (1992), Nabutosky and Ben-Av (1993), Kontsevich (1994).

[73] In the history of mathematics there has been a long-standing dialectic between the development of its "pure" and "applied" branches (Struik 1987). Of course, the "applications" traditionally privileged in this context have been those profitable to capitalists or useful to their military forces: for example, number theory has been developed largely for its applications in cryptography (Loxton 1990). See also Hardy (1967, 120–121, 131–132).

[74] The equal representation of all boundary conditions is also suggested by Chew's bootstrap theory of "subatomic democracy": see Chew (1977) for an introduction, and see Morris (1988) and Markley (1992) for philosophical analysis.

Transgressing the Boundaries: Towards a Liberatory Science

Over the past two decades there has been extensive discussion among critical theorists with regard to the characteristics of modernist versus postmodernist culture; and in recent years these dialogues have begun to devote detailed attention to the specific problems posed by the natural sciences.[75] In particular, Madsen and Madsen have recently given a very clear summary of the characteristics of modernist versus postmodernist science. They posit two criteria for a postmodern science:

> A simple criterion for science to qualify as postmodern is that it be free from any dependence on the concept of objective truth. By this criterion, for example, the complementarity interpretation of quantum physics due to Niels Bohr and the Copenhagen school is seen as postmodernist.[76]

Clearly, quantum gravity is in this respect an archetypal postmodernist science. Secondly,

> The other concept which can be taken as being fundamental to postmodern science is that of *essentiality*. Postmodern scientific theories are constructed from those theoretical elements which are essential for the consistency and utility of the theory.[77]

Thus, quantities or objects which are in principle unobservable — such as space-time points, exact particle positions, or quarks and gluons — ought not to be introduced into the theory.[78] While much of modern physics is excluded by this criterion,

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[75] Among the large body of works from a diversity of politically progressive perspectives, the books by Merchant (1980), Keller (1985), Harding (1986), Aronowitz (1988b), Haraway (1991) and Ross (1991) have been especially influential. See also the references cited below.

[76] Madsen and Madsen (1990, 471). The main limitation of the Madsen–Madsen analysis is that it is essentially apolitical; and it hardly needs to be pointed out that disputes over what is *true* can have a profound effect on, and are in turn profoundly affected by, disputes over *political projects*. Thus, Markley (1992, 270) makes a point similar to that of Madsen–Madsen, but rightly situates it in its political context:

> Radical critiques of science that seek to escape the constraints of deterministic dialectics must also give over narrowly conceived debates about realism and truth to investigate what kind of realities — political realities — might be engendered by a dialogical bootstrapping. Within a dialogically agitated environment, debates about reality become, in practical terms, irrelevant. "Reality," finally, is a historical construct.

See Markley (1992, 266–272) and Hobsbawm (1993, 63–64) for further discussion of the political implications.

[77] Madsen and Madsen (1990, 471–472).

[78] Aronowitz (1988b, 292–293) makes a slightly different, but equally cogent, criticism of quantum chromodynamics (the currently hegemonic theory representing nucleons as permanently bound states of quarks and gluons): drawing on the work of Pickering (1984), he notes that

> in his [Pickering's] account, quarks are the name assigned to (absent) phenomena that cohere with particle rather than field theories, which, in each case, offer different,

quantum gravity again qualifies: in the passage from classical general relativity to the quantized theory, space-time points (and indeed the space-time manifold itself) have disappeared from the theory.

However, these criteria, admirable as they are, are insufficient for a *liberatory* postmodern science: they liberate human beings from the tyranny of "absolute truth" and "objective reality", but not necessarily from the tyranny of other human beings. In Andrew Ross' words, we need a science "that will be publicly answerable and of some service to progressive interests."[79] From a feminist standpoint, Kelly Oliver makes a similar argument:

> ... in order to be revolutionary, feminist theory cannot claim to describe what exists, or, "natural facts." Rather, feminist theories should be political tools, strategies for overcoming oppression in specific concrete situations. The goal, then, of feminist theory, should be to develop *strategic* theories — not true theories, not false theories, but strategic theories.[80]

How, then, is this to be done?

In what follows, I would like to discuss the outlines of a liberatory postmodern science on two levels: first, with regard to general themes and attitudes; and second,

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> although equally plausible, explanations for the same (inferred) observation. That the majority of the scientific community chose one over another is a function of scientists' preference for the tradition rather than the validity of explanation.
>
> However, Pickering does not reach back far enough into the history of physics to find the basis of the research tradition from which the quark explanation emanates. It may not be found inside the tradition but in the ideology of science, in the differences behind field versus particle theories, simple versus complex explanations, the bias toward certainty rather than indeterminateness.

Along very similar lines, Markley (1992, 269) observes that physicists' preference for quantum chromodynamics over Chew's bootstrap theory of "subatomic democracy" (Chew 1977) is a result of ideology rather than data:

> It is not surprising, in this regard, that bootstrap theory has fallen into relative disfavor among physicists seeking a GUT (Grand Unified Theory) or TOE (Theory of Everything) to explain the structure of the universe. Comprehensive theories that explain "everything" are products of the privileging of coherence and order in western science. The choice between bootstrap theory and theories of everything that confronts physicists does *not* have to do primarily with the truth-value offered by these accounts of available data but with the narrative structures — indeterminate or deterministic — into which these data are placed and by which they are interpreted.

Unfortunately, the vast majority of physicists are not yet aware of these incisive critiques of one of their most fervently-held dogmas.

For another critique of the hidden ideology of contemporary particle physics, see Kroker *et al.* (1989, 158–162, 204–207). The style of this critique is rather too Baudrillardian for my staid taste, but the content is (except for a few minor inaccuracies) right on target.

[79]Ross (1991, 29). For an amusing example of how this modest demand has driven right-wing scientists into fits of apoplexy ("frighteningly Stalinist" is the chosen epithet), see Gross and Levitt (1994, 91).

[80]Oliver (1989, 146).

with regard to political goals and strategies.

One characteristic of the emerging postmodern science is its stress on nonlinearity and discontinuity: this is evident, for example, in chaos theory and the theory of phase transitions as well as in quantum gravity.[81] At the same time, feminist thinkers have pointed out the need for an adequate analysis of fluidity, in particular turbulent fluidity.[82] These two themes are not as contradictory as it might at first appear: turbulence connects with strong nonlinearity, and smoothness/fluidity is sometimes associated with discontinuity (e.g. in catastrophe theory[83]); so a synthesis is by no means out of the question.

Secondly, the postmodern sciences deconstruct and transcend the Cartesian metaphysical distinctions between humankind and Nature, observer and observed, Subject and Object. Already quantum mechanics, earlier in this century, shattered the ingenuous Newtonian faith in an objective, pre-linguistic world of material objects "out there"; no longer could we ask, as Heisenberg put it, whether "particles exist in space and time objectively". But Heisenberg's formulation still presupposes the objective existence of space and time as the neutral, unproblematic arena in which quantized particle-waves interact (albeit indeterministically); and it is precisely this would-be arena that quantum gravity problematizes. Just as quantum mechanics informs us that the position and momentum of a particle are brought into being only by the act of observation, so quantum gravity informs us that space and time themselves are contextual, their meaning defined only relative to the mode of observation.[84]

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[81] While chaos theory has been deeply studied by cultural analysts — see e.g. Hayles (1990,1991), Argyros (1991), Best (1991), Young (1991,1992), Assad (1993) among many others — the theory of phase transitions has passed largely unremarked. (One exception is the discussion of the renormalization group in Hayles (1990, 154–158).) This is a pity, because discontinuity and the emergence of multiple scales are central features in this theory; and it would be interesting to know how the development of these themes in the 1970's and afterwards is connected to trends in the wider culture. I therefore suggest this theory as a fruitful field for future research by cultural analysts. Some theorems on discontinuity which may be relevant to this analysis can be found in Van Enter, Fernández and Sokal (1993).

[82] Irigaray (1985), Hayles (1992). See, however, Schor (1989) for a critique of Irigaray's undue deference toward conventional (male) science, particularly physics.

[83] Thom (1975,1990), Arnol'd (1992).

[84] Concerning the Cartesian/Baconian metaphysics, Robert Markley (1991, 6) has observed that

> Narratives of scientific progress depend upon imposing binary oppositions — true/false, right/wrong — on theoretical and experimental knowledge, privileging meaning over noise, metonymy over metaphor, monological authority over dialogical contention. ... [T]hese attempts to fix nature are ideologically coercive as well as descriptively limited. They focus attention only on the small range of phenomena — say, linear dynamics — which seem to offer easy, often idealized ways of modeling and interpreting humankind's relationship to the universe.

While this observation is informed primarily by chaos theory — and secondarily by nonrelativistic quantum mechanics — it in fact summarizes beautifully the radical challenge to modernist metaphysics posed by quantum gravity.

Thirdly, the postmodern sciences overthrow the static ontological categories and hierarchies characteristic of modernist science. In place of atomism and reductionism, the new sciences stress the dynamic web of relationships between the whole and the part; in place of fixed individual essences (e.g. Newtonian particles), they conceptualize interactions and flows (e.g. quantum fields). Intriguingly, these homologous features arise in numerous seemingly disparate areas of science, from quantum gravity to chaos theory to the biophysics of self-organizing systems. In this way, the postmodern sciences appear to be converging on a new epistemological paradigm, one that may be termed an *ecological* perspective, broadly understood as "recogniz[ing] the fundamental interdependence of all phenomena and the embeddedness of individuals and societies in the cyclical patterns of nature."[85]

A fourth aspect of postmodern science is its self-conscious stress on symbolism and representation. As Robert Markley points out, the postmodern sciences are increasingly transgressing disciplinary boundaries, taking on characteristics that had heretofore been the province of the humanities:

> Quantum physics, hadron bootstrap theory, complex number theory, and chaos theory share the basic assumption that reality cannot be described in linear terms, that nonlinear — and unsolvable — equations are the only means possible to describe a complex, chaotic, and non-deterministic reality. These postmodern theories are — significantly — all metacritical in the sense that they foreground themselves as metaphors rather than as "accurate" descriptions of reality. In terms that are more familiar to literary theorists than to theoretical physicists, we might say that these attempts by scientists to develop new strategies of description represent notes towards a theory of theories, of how representation — mathematical, experimental, and verbal — is inherently complex and problematizing, not a solution but part of the semiotics of investigating the universe.[86,87]

From a different starting point, Aronowitz likewise suggests that a liberatory science may arise from interdisciplinary sharing of epistemologies:

> ... natural objects are also socially constructed. It is not a question of whether these natural objects, or, to be more precise, the objects of natural scientific

[85] Capra (1988, 145). One caveat: I have strong reservations about Capra's use here of the word "cyclical", which if interpreted too literally could promote a politically regressive quietism. For further analyses of these issues, see Bohm (1980), Merchant (1980,1992), Berman (1981), Prigogine and Stengers (1984), Bowen (1985), Griffin (1988), Kitchener (1988), Callicott (1989, chaps. 6 and 9), Shiva (1990), Best (1991), Haraway (1991,1994), Mathews (1991), Morin (1992), Santos (1992) and Wright (1992).

[86] Markley (1992, 264). A minor quibble: It is not clear to me that complex number theory, which is a new and still quite speculative branch of mathematical physics, ought to be accorded the same epistemological status as the three firmly established sciences cited by Markley.

[87] See Wallerstein (1993, 17–20) for an incisive and closely analogous account of how the postmodern physics is beginning to borrow ideas from the historical social sciences; and see Santos (1989,1992) for a more detailed development.

> knowledge, exist independently of the act of knowing. This question is answered by the assumption of "real" time as opposed to the presupposition, common among neo-Kantians, that time always has a referent, that temporality is therefore a relative, not an unconditioned, category. Surely, the earth evolved long before life on earth. The question is whether objects of natural scientific knowledge are constituted outside the social field. If this is possible, we can assume that science or art may develop procedures that effectively neutralize the effects emanating from the means by which we produce knowledge/art. Performance art may be such an attempt.[88]

Finally, postmodern science provides a powerful refutation of the authoritarianism and elitism inherent in traditional science, as well as an empirical basis for a democratic approach to scientific work. For, as Bohr noted, "a complete elucidation of one and the same object may require diverse points of view which defy a unique description" — this is quite simply a fact about the world, much as the self-proclaimed empiricists of modernist science might prefer to deny it. In such a situation, how can a self-perpetuating secular priesthood of credentialed "scientists" purport to maintain a monopoly on the production of scientific knowledge? (Let me emphasize that I am in no way opposed to specialized scientific training; I object only when an elite caste seeks to impose its canon of "high science", with the aim of excluding *a priori* alternative forms of scientific production by non-members.[89])

The content and methodology of postmodern science thus provide powerful intellectual support for the progressive political project, understood in its broadest sense: the transgressing of boundaries, the breaking down of barriers, the radical

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[88] Aronowitz (1988b, 344).

[89] At this point, the traditional scientist's response is that work not conforming to the evidentiary standards of conventional science is fundamentally *irrational*, i.e. logically flawed and therefore not worthy of credence. But this refutation is insufficient: for, as Porush (1993) has lucidly observed, modern mathematics and physics have *themselves* admitted a powerful "intrusion of the irrational" in quantum mechanics and Gödel's theorem — although, understandably, like the Pythagoreans 24 centuries ago, modernist scientists have attempted to exorcise this unwanted irrational element as best they could. Porush makes a powerful plea for a "post-rational epistemology" that would retain the best of conventional Western science while validating alternative ways of knowing.

Note also that Jacques Lacan, from a quite different starting point, came long ago to a similar appreciation of the inevitable role of irrationality in modern mathematics:

> If you'll permit me to use one of those formulas which come to me as I write my notes, human life could be defined as a calculus in which zero was irrational. This formula is just an image, a mathematical metaphor. When I say "irrational," I'm referring not to some unfathomable emotional state but precisely to what is called an imaginary number. The square root of minus one doesn't correspond to anything that is subject to our intuition, anything real — in the mathematical sense of the term — and yet, it must be conserved, along with its full function.

[Lacan (1977, 28–29), seminar originally given in 1959.]

For further reflections on irrationality in modern mathematics, see Solomon (1988, 76) and Bloor (1991, 122–125).

democratization of all aspects of social, economic, political and cultural life.[90] Conversely, one part of this project must involve the construction of a new and truly progressive science that can serve the needs of such a democratized society-to-be. As Markley observes, there seem to be two more-or-less mutually exclusive choices available to the progressive community:

> On the one hand, politically progressive scientists can try to recuperate existing practices for moral values they uphold, arguing that their right-wing enemies are defacing nature and that they, the counter-movement, have access to the truth. [But] the state of the biosphere — air pollution, water pollution, disappearing rain forests, thousands of species on the verge of extinction, large areas of land burdened far beyond their carrying capacity, nuclear power plants, nuclear weapons, clearcuts where there used to be forests, starvation, malnutrition, disappearing wetlands, nonexistent grass lands, and a rash of environmentally caused diseases — suggests that the realist dream of scientific progress, of recapturing rather than revolutionizing existing methodologies and technologies, is, at worst, irrelevant to a political struggle that seeks something more than a reenactment of state socialism.[91]

The alternative is a profound reconception of science as well as politics:

> [T]he dialogical move towards redefining systems, of seeing the world not only as an ecological whole but as a set of competing systems — a world held together by the tensions among various natural and human interests — offers the possibility of redefining what science is and what it does, of restructuring deterministic schemes of scientific education in favor of ongoing dialogues about how we intervene in our environment.[92]

It goes without saying that postmodernist science unequivocally favors the latter, deeper approach.

In addition to redefining the content of science, it is imperative to restructure and redefine the institutional loci in which scientific labor takes place — universities, government labs, and corporations — and reframe the reward system that pushes scientists to become, often against their own better instincts, the hired guns of capitalists and the military. As Aronowitz has noted, "One third of the 11,000 physics graduate students in the United States are in the single subfield of solid state physics, and all of them will be able to get jobs in that subfield."[93] By

[90] See e.g. Aronowitz (1994) and the discussion following it.

[91] Markley (1992, 271).

[92] Markley (1992, 271). Along parallel lines, Donna Haraway (1991, 191–192) has argued eloquently for a democratic science comprising "partial, locatable, critical knowledges sustaining the possibility of webs of connections called solidarity in politics and shared conversations in epistemology" and founded on "a doctrine and practice of objectivity that privileges contestation, deconstruction, passionate construction, webbed connections, and hope for transformation of systems of knowledge and ways of seeing." These ideas are further developed in Haraway (1994) and Doyle (1994).

[93] Aronowitz (1988b, 351). Although this observation appeared in 1988, it is all the more true today.

contrast, there are few jobs available in either quantum gravity or environmental physics.

But all this is only a first step: the fundamental goal of any emancipatory movement must be to demystify and democratize the production of scientific knowledge, to break down the artificial barriers that separate "scientists" from "the public". Realistically, this task must start with the younger generation, through a profound reform of the educational system.[94] The teaching of science and mathematics must be purged of its authoritarian and elitist characteristics[95], and the content of these subjects enriched by incorporating the insights of the feminist[96], queer[97], multiculturalist[98] and ecological[99] critiques.

Finally, the content of any science is profoundly constrained by the language within which its discourses are formulated; and mainstream Western physical science has, since Galileo, been formulated in the language of mathematics.[100,101] But

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[94] Freire (1970), Aronowitz and Giroux (1991,1993).

[95] For an example in the context of the Sandinista revolution, see Sokal (1987).

[96] Merchant (1980), Easlea (1981), Keller (1985,1992), Harding (1986,1991), Haraway (1989,1991), Plumwood (1993a). See Wylie *et al.* (1990) for an extensive bibliography. The feminist critique of science has, not surprisingly, been the object of a bitter right-wing counterattack. For a sampling, see Levin (1988), Haack (1992,1993), Sommers (1994), Gross and Levitt (1994, chap. 5) and Patai and Koertge (1994).

[97] Trebilcot (1988), Hamill (1994).

[98] Ezeabasili (1977), Van Sertima (1983), Frye (1987), Sardar (1988), Adams (1990), Nandy (1990), Alvares (1992), Harding (1994). As with the feminist critique, the multiculturalist perspective has been ridiculed by right-wing critics, with a condescension that in some cases borders on racism. See e.g. Ortiz de Montellano (1991), Martel (1991/92), Hughes (1993, chap. 2) and Gross and Levitt (1994, 203–214).

[99] Merchant (1980,1992), Berman (1981), Callicott (1989, chaps. 6 and 9), Mathews (1991), Wright (1992), Plumwood (1993a), Ross (1994).

[100] See Wojciehowski (1991) for a deconstruction of Galileo's rhetoric, in particular his claim that the mathematico-scientific method can lead to direct and reliable knowledge of "reality".

[101] A very recent but important contribution to the philosophy of mathematics can be found in the work of Deleuze and Guattari (1994, chap. 5). Here they introduce the philosophically fruitful notion of a "functive" [Fr. *fonctif*], which is neither a function [Fr. *fonction*] nor a functional [Fr. *fonctionnelle*] but rather a more basic conceptual entity:

> The object of science is not concepts but rather functions that are presented as propositions in discursive systems. The elements of functions are called *functives*. [p. 117]

This apparently simple idea has surprisingly subtle and far-reaching consequences; its elucidation requires a detour into chaos theory (see also Rosenberg 1993 and Canning 1994):

> ... the first difference between science and philosophy is their respective attitudes toward chaos. Chaos is defined not so much by its disorder as by the infinite speed with which every form taking shape in it vanishes. It is a void that is not a nothingness but a *virtual*, containing all possible particles and drawing out all possible forms, which spring up only to disappear immediately, without consistency or reference, without consequence. Chaos is an infinite speed of birth and disappearance. [pp. 117–118]

whose mathematics? The question is a fundamental one, for, as Aronowitz has observed, "neither logic nor mathematics escapes the 'contamination' of the social."[102] And as feminist thinkers have repeatedly pointed out, in the present culture this contamination is overwhelmingly capitalist, patriarchal and militaristic: "mathematics is portrayed as a woman whose nature desires to be the conquered Other."[103,104]

But science, unlike philosophy, cannot cope with infinite speeds:

> ... it is by slowing down that matter, as well as the scientific thought able to penetrate it [*sic*] with propositions, is actualized. A function is a Slow-motion. Of course, science constantly advances accelerations, not only in catalysis but in particle accelerators and expansions that move galaxies apart. However, the primordial slowing down is not for these phenomena a zero-instant with which they break but rather a condition coextensive with their whole development. To slow down is to set a limit in chaos to which all speeds are subject, so that they form a variable determined as abscissa, at the same time as the limit forms a universal constant that cannot be gone beyond (for example, a maximum degree of contraction). *The first functives are therefore the limit and the variable*, and reference is a relationship between values of the variable or, more profoundly, the relationship of the variable, as abscissa of speeds, with the limit. [pp. 118–119, emphasis mine]

A rather intricate further analysis (too lengthy to quote here) leads to a conclusion of profound methodological importance for those sciences based on mathematical modelling:

> The respective independence of variables appears in mathematics when one of them is at a higher power than the first. That is why Hegel shows that variability in the function is not confined to values that can be changed ($\frac{2}{3}$ and $\frac{4}{6}$) or are left undetermined ($a = 2b$) but requires one of the variables to be at a higher power ($y^2/x = P$). [p. 122]

(Note that the English translation inadvertently writes $y^{2/x} = P$, an amusing error that thoroughly mangles the logic of the argument.)

Surprisingly for a technical philosophical work, this book (*Qu'est-ce que la philosophie?*) was a best-seller in France in 1991. It has recently appeared in English translation, but is, alas, unlikely to compete successfully with Rush Limbaugh and Howard Stern for the best-seller lists in this country.

[102] Aronowitz (1988b, 346). For a vicious right-wing attack on this proposition, see Gross and Levitt (1994, 52–54). See Ginzberg (1989), Cope-Kasten (1989), Nye (1990) and Plumwood (1993b) for lucid feminist critiques of conventional (masculinist) mathematical logic, in particular the *modus ponens* and the syllogism. Concerning the *modus ponens*, see also Woolgar (1988, 45–46) and Bloor (1991, 182); and concerning the syllogism, see also Woolgar (1988, 47–48) and Bloor (1991, 131–135). For an analysis of the social images underlying mathematical conceptions of infinity, see Harding (1986, 50). For a demonstration of the social contextuality of mathematical statements, see Woolgar (1988, 43) and Bloor (1991, 107–130).

[103] Campbell and Campbell-Wright (1993, 11). See Merchant (1980) for a detailed analysis of the themes of control and domination in Western mathematics and science.

[104] Let me mention in passing two other examples of sexism and militarism in mathematics that to my knowledge have not been noticed previously:

The first concerns the theory of branching processes, which arose in Victorian England from the "problem of the extinction of families", and which now plays a key role *inter alia* in the analysis of nuclear chain reactions (Harris 1963). In the seminal (and this sexist word is apt) paper on the subject, Francis Galton and the Reverend H.W. Watson wrote (1874):

Thus, a liberatory science cannot be complete without a profound revision of the canon of mathematics.[105] As yet no such emancipatory mathematics exists, and we can only speculate upon its eventual content. We can see hints of it in the multidimensional and nonlinear logic of fuzzy systems theory[106]; but this approach is still heavily marked by its origins in the crisis of late-capitalist production relations.[107] Catastrophe theory[108], with its dialectical emphases on smoothness/discontinuity and metamorphosis/unfolding, will indubitably play a major role in the future mathematics; but much theoretical work remains to be done before this approach can become a concrete tool of progressive political praxis.[109] Finally, chaos theory — which provides our deepest insights into the ubiquitous yet mysterious phenomenon of nonlinearity — will be central to all future mathematics. And yet, these images of the future mathematics must remain but the haziest glimmer: for, alongside these three young branches in the tree of science, there will arise new trunks and branches — entire new theoretical frameworks — of which we, with our present ideological blinders, cannot yet even conceive.

> The decay of the families of men who occupied conspicuous positions in past times has been a subject of frequent research, and has given rise to various conjectures ... The instances are very numerous in which surnames that were once common have since become scarce or have wholly disappeared. The tendency is universal, and, in explanation of it, the conclusion has hastily been drawn that a rise in physical comfort and intellectual capacity is necessarily accompanied by a diminution in 'fertility' ...
>
> Let $p_0, p_1, p_2, \ldots$ be the respective probabilities that a man has $0, 1, 2, \ldots$ sons, let each son have the same probability of sons of his own, and so on. What is the probability that the male line is extinct after r generations, and more generally what is the probability for any given number of descendants in the male line in any given generation?

One cannot fail to be charmed by the quaint implication that human males reproduce asexually; nevertheless, the classism, social-Darwinism and sexism in this passage are obvious.

The second example is Laurent Schwartz's 1973 book on *Radon Measures*. While technically quite interesting, this work is imbued, as its title makes plain, with the pro-nuclear-energy worldview that has been characteristic of French science since the early 1960's. Sadly, the French left — especially but by no means solely the PCF — has traditionally been as enthusiastic for nuclear energy as the right (see Touraine *et al.* 1980).

[105] Just as liberal feminists are frequently content with a minimal agenda of legal and social equality for women and "pro-choice", so liberal (and even some socialist) mathematicians are often content to work within the hegemonic Zermelo-Fraenkel framework (which, reflecting its nineteenth-century liberal origins, already incorporates the axiom of equality) supplemented only by the axiom of choice. But this framework is grossly insufficient for a liberatory mathematics, as was proven long ago by Cohen (1966).

[106] Kosko (1993).

[107] Fuzzy systems theory has been heavily developed by transnational corporations — first in Japan and later elsewhere — to solve practical problems of efficiency in labor-displacing automation.

[108] Thom (1975,1990), Arnol'd (1992).

[109] An interesting start is made by Schubert (1989).

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Works Cited

Adams, Hunter Havelin III. 1990. African and African-American contributions to science and technology. In *African-American Baseline Essays*. Portland, Ore.: Multnomah School District 1J, Portland Public Schools.

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

Alexander, Stephanie B., I. David Berg and Richard L. Bishop. 1993. Geometric curvature bounds in Riemannian manifolds with boundary. *Transactions of the American Mathematical Society* **339**: 703–716.

Althusser, Louis. 1993. *Écrits sur la Psychanalyse: Freud et Lacan*. Paris: Stock/IMEC.

Alvares, Claude. 1992. *Science, Development and Violence: The Revolt against Modernity*. Delhi: Oxford University Press.

Alvarez-Gaumé, Luís. 1985. Topology and anomalies. In *Mathematics and Physics: Lectures on Recent Results*, vol. 2, pp. 50–83, edited by L. Streit. Singapore: World Scientific.

Argyros, Alexander J. 1991. *A Blessed Rage for Order: Deconstruction, Evolution, and Chaos*. Ann Arbor: University of Michigan Press.

Arnol'd, Vladimir I. 1992. *Catastrophe Theory*. 3^{rd} ed. Translated by G.S. Wassermann and R.K. Thomas. Berlin: Springer.

Aronowitz, Stanley. 1981. *The Crisis in Historical Materialism: Class, Politics and Culture in Marxist Theory*. New York: Praeger.

Aronowitz, Stanley. 1988a. The production of scientific knowledge: Science, ideology, and Marxism. In *Marxism and the Interpretation of Culture*, pp. 519–541, edited by Cary Nelson and Lawrence Grossberg. Urbana and Chicago: University of Illinois Press.

Aronowitz, Stanley. 1988b. *Science as Power: Discourse and Ideology in Modern Society*. Minneapolis: University of Minnesota Press.

Aronowitz, Stanley. 1994. The situation of the left in the United States. *Socialist Review* **23**(3): 5–79.

Aronowitz, Stanley and Henry A. Giroux. 1991. *Postmodern Education: Politics, Culture, and Social Criticism*. Minneapolis: University of Minnesota Press.

Aronowitz, Stanley and Henry A. Giroux. 1993. *Education Still Under Siege*. Westport, Conn.: Bergin & Garvey.

Ashtekar, Abhay, Carlo Rovelli and Lee Smolin. 1992. Weaving a classical metric with quantum threads. *Physical Review Letters* **69**: 237–240.

Aspect, Alain, Jean Dalibard and Gérard Roger. 1982. Experimental test of Bell's inequalities using time-varying analyzers. *Physical Review Letters* **49**: 1804–1807.

Assad, Maria L. 1993. Portrait of a nonlinear dynamical system: The discourse of Michel Serres. *SubStance* **71/72**: 141–152.

Back, Kurt W. 1992. This business of topology. *Journal of Social Issues* **48**(2): 51–66.

Bell, John S. 1987. *Speakable and Unspeakable in Quantum Mechanics: Collected Papers on Quantum Philosophy*. New York: Cambridge University Press.

Berman, Morris. 1981. *The Reenchantment of the World*. Ithaca, N.Y.: Cornell University Press.

Best, Steven. 1991. Chaos and entropy: Metaphors in postmodern science and social theory. *Science as Culture* **2**(2) (no. 11): 188–226.

Bloor, David. 1991. *Knowledge and Social Imagery*. 2^{nd} ed. Chicago: University of Chicago Press.

Bohm, David. 1980. *Wholeness and the Implicate Order.* London: Routledge & Kegan Paul.

Bohr, Niels. 1958. Natural philosophy and human cultures. In *Essays 1932–1957 on Atomic Physics and Human Knowledge* (The Philosophical Writings of Niels Bohr, Volume II), pp. 23–31. New York: Wiley.

Bohr, Niels. 1963. Quantum physics and philosophy — causality and complementarity. In *Essays 1958–1962 on Atomic Physics and Human Knowledge* (The Philosophical Writings of Niels Bohr, Volume III), pp. 1–7. New York: Wiley.

Booker, M. Keith. 1990. Joyce, Planck, Einstein, and Heisenberg: A relativistic quantum mechanical discussion of *Ulysses*. *James Joyce Quarterly* **27**: 577–586.

Boulware, David G. and S. Deser. 1975. Classical general relativity derived from quantum gravity. *Annals of Physics* **89**: 193–240.

Bourbaki, Nicolas. 1970. *Théorie des Ensembles.* Paris: Hermann.

Bowen, Margarita. 1985. The ecology of knowledge: Linking the natural and social sciences. *Geoforum* **16**: 213–225.

Bricmont, Jean. 1994. Contre la philosophie de la mécanique quantique. Texte d'une communication faite au colloque "Faut-il promouvoir les échanges entre les sciences et la philosophie?", Louvain-la-Neuve (Belgium), 24–25 mars 1994.

Briggs, John and F. David Peat. 1984. *Looking Glass Universe: The Emerging Science of Wholeness*. New York: Cornerstone Library.

Brooks, Roger and David Castor. 1990. Morphisms between supersymmetric and topological quantum field theories. *Physics Letters B* **246**: 99–104.

Callicott, J. Baird. 1989. *In Defense of the Land Ethic: Essays in Environmental Philosophy*. Albany, N.Y.: State University of New York Press.

Campbell, Mary Anne and Randall K. Campbell-Wright. 1993. Toward a feminist algebra. Paper presented at a meeting of the Mathematical Association of America (San Antonio, Texas). To appear in *Teaching the Majority: Science, Mathematics, and Engineering That Attracts Women*, edited by Sue V. Rosser. New York: Teachers College Press, 1995.

Canning, Peter. 1994. The crack of time and the ideal game. In *Gilles Deleuze and the Theater of Philosophy*, pp. 73–98, edited by Constantin V. Boundas and Dorothea Olkowski. New York: Routledge.

Capra, Fritjof. 1975. *The Tao of Physics: An Exploration of the Parallels Between Modern Physics and Eastern Mysticism*. Berkeley, Calif.: Shambhala.

Capra, Fritjof. 1988. The role of physics in the current change of paradigms. In *The World View of Contemporary Physics: Does It Need a New Metaphysics?*, pp. 144–155, edited by Richard F. Kitchener. Albany, N.Y.: State University of New York Press.

Caracciolo, Sergio, Robert G. Edwards, Andrea Pelissetto and Alan D. Sokal. 1993. Wolff-type embedding algorithms for general nonlinear σ-models. *Nuclear Physics B* **403**: 475–541.

Chew, Geoffrey. 1977. Impasse for the elementary-particle concept. In *The Sciences Today*, pp. 366–399, edited by Robert M. Hutchins and Mortimer Adler. New York: Arno Press.

Chomsky, Noam. 1979. *Language and Responsibility*. Translated by John Viertel. New York: Pantheon.

Cohen, Paul J. 1966. *Set Theory and the Continuum Hypothesis*. New York: Benjamin.

Coleman, Sidney. 1993. Quantum mechanics in your face. Lecture at New York University, November 12, 1993.

Cope-Kasten, Vance. 1989. A portrait of dominating rationality. *Newsletters on Computer Use, Feminism, Law, Medicine, Teaching (American Philosophical Association)* **88**(2) (March): 29–34.

Corner, M.A. 1966. Morphogenetic field properties of the forebrain area of the neural plate in an anuran. *Experientia* **22**: 188–189.

Craige, Betty Jean. 1982. *Literary Relativity: An Essay on Twentieth-Century Narrative*. Lewisburg: Bucknell University Press.

Culler, Jonathan. 1982. *On Deconstruction: Theory and Criticism after Structuralism*. Ithaca, N.Y.: Cornell University Press.

Dean, Tim. 1993. The psychoanalysis of AIDS. *October* **63**: 83–116.

Deleuze, Gilles and Félix Guattari. 1994. *What is Philosophy?* Translated by Hugh Tomlinson and Graham Burchell. New York: Columbia University Press.

Derrida, Jacques. 1970. Structure, sign and play in the discourse of the human sciences. In *The Languages of Criticism and the Sciences of Man: The Structuralist Controversy*, pp. 247–272, edited by Richard Macksey and Eugenio Donato. Baltimore: Johns Hopkins Press.

Doyle, Richard. 1994. Dislocating knowledge, thinking out of joint: Rhizomatics, *Caenorhabditis elegans* and the importance of being multiple. *Configurations: A Journal of Literature, Science, and Technology* **2**: 47–58.

Dürr, Detlef, Sheldon Goldstein and Nino Zanghí. 1992. Quantum equilibrium and the origin of absolute uncertainty. *Journal of Statistical Physics* **67**: 843–907.

Easlea, Brian. 1981. *Science and Sexual Oppression: Patriarchy's Confrontation with Women and Nature*. London: Weidenfeld and Nicolson.

Eilenberg, Samuel and John C. Moore. 1965. *Foundations of Relative Homological Algebra*. Providence, R.I.: American Mathematical Society.

Eilenberg, Samuel and Norman E. Steenrod. 1952. *Foundations of Algebraic Topology*. Princeton, N.J.: Princeton University Press.

Einstein, Albert and Leopold Infeld. 1961. *The Evolution of Physics*. New York: Simon and Schuster.

Ezeabasili, Nwankwo. 1977. *African Science: Myth or Reality?* New York: Vantage Press.

Feyerabend, Paul K. 1975. *Against Method: Outline of an Anarchistic Theory of Knowledge*. London: New Left Books.

Freire, Paulo. 1970. *Pedagogy of the Oppressed*. Translated by Myra Bergman Ramos. New York: Continuum.

Froula, Christine. 1985. Quantum physics/postmodern metaphysics: The nature of Jacques Derrida. *Western Humanities Review* **39**: 287–313.

Frye, Charles A. 1987. Einstein and African religion and philosophy: The hermetic parallel. In *Einstein and the Humanities*, pp. 59–70, edited by Dennis P. Ryan. New York: Greenwood Press.

Galton, Francis and H.W. Watson. 1874. On the probability of the extinction of families. *Journal of the Anthropological Institute of Great Britain and Ireland* **4**: 138–144.

Gierer, A., R.C. Leif, T. Maden and J.D. Watson. 1978. Physical aspects of generation of morphogenetic fields and tissue forms. In *Differentiation and Development*, edited by F. Ahmad, J. Schultz, T.R. Russell and R. Werner. New York: Academic Press.

Ginzberg, Ruth. 1989. Feminism, rationality, and logic. *Newsletters on Computer Use, Feminism, Law, Medicine, Teaching (American Philosophical Association)* **88**(2) (March): 34–39.

Gleick, James. 1987. *Chaos: Making a New Science*. New York: Viking.

Gödel, Kurt. 1949. An example of a new type of cosmological solutions of Einstein's field equations of gravitation. *Reviews of Modern Physics* **21**: 447–450.

Goldstein, Rebecca. 1983. *The Mind-Body Problem*. New York: Random House.

Granero-Porati, M.I. and A. Porati. 1984. Temporal organization in a morphogenetic field. *Journal of Mathematical Biology* **20**: 153–157.

Granon-Lafont, Jeanne. 1985. *La Topologie Ordinaire de Jacques Lacan*. Paris: Point Hors Ligne.

Granon-Lafont, Jeanne. 1990. *Topologie Lacanienne et Clinique Analytique*. Paris: Point Hors Ligne.

Green, Michael B., John H. Schwarz and Edward Witten. 1987. *Superstring Theory*. 2 vols. New York: Cambridge University Press.

Greenberg, Valerie D. 1990. *Transgressive Readings: The Texts of Franz Kafka and Max Planck*. Ann Arbor: University of Michigan Press.

Greenberger, D.M., M.A. Horne and Z. Zeilinger. 1989. Going beyond Bell's theorem. In *Bell's Theorem, Quantum Theory and Conceptions of the Universe*, pp. 73–76, edited by M. Kafatos. Dordrecht: Kluwer.

Greenberger, D.M., M.A. Horne, A. Shimony and Z. Zeilinger. 1990. Bell's theorem without inequalities. *American Journal of Physics* **58**: 1131–1143.

Griffin, David Ray, ed. 1988. *The Reenchantment of Science: Postmodern Proposals*. Albany, N.Y.: State University of New York Press.

Gross, Paul R. and Norman Levitt. 1994. *Higher Superstition: The Academic Left and its Quarrels with Science.* Baltimore: Johns Hopkins University Press.

Haack, Susan. 1992. Science 'from a feminist perspective'. *Philosophy* **67**: 5–18.

Haack, Susan. 1993. Epistemological reflections of an old feminist. *Reason Papers* **18** (fall): 31–43.

Hamber, Herbert W. 1992. Phases of four-dimensional simplicial quantum gravity. *Physical Review D* **45**: 507–512.

Hamill, Graham. 1994. The epistemology of expurgation: Bacon and *The Masculine Birth of Time*. In *Queering the Renaissance*, pp. 236–252, edited by Jonathan Goldberg. Durham, N.C.: Duke University Press.

Hamza, Hichem. 1990. Sur les transformations conformes des variétés riemanniennes à bord. *Journal of Functional Analysis* **92**: 403–447.

Haraway, Donna J. 1989. *Primate Visions: Gender, Race, and Nature in the World of Modern Science*. New York: Routledge.

Haraway, Donna J. 1991. *Simians, Cyborgs, and Women: The Reinvention of Nature*. New York: Routledge.

Haraway, Donna J. 1994. A game of cat's cradle: Science studies, feminist theory, cultural studies. *Configurations: A Journal of Literature, Science, and Technology* **2**: 59–71.

Harding, Sandra. 1986. *The Science Question in Feminism.* Ithaca: Cornell University Press.

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

Harding, Sandra. 1994. Is science multicultural? Challenges, resources, opportunities, uncertainties. *Configurations: A Journal of Literature, Science, and Technology* **2**: 301–330.

Hardy, G.H. 1967. *A Mathematician's Apology*. Cambridge: Cambridge University Press.

Harris, Theodore E. 1963. *The Theory of Branching Processes.* Berlin: Springer.

Hayles, N. Katherine. 1984. *The Cosmic Web: Scientific Field Models and Literary Strategies in the Twentieth Century*. Ithaca: Cornell University Press.

Hayles, N. Katherine. 1990. *Chaos Bound: Orderly Disorder in Contemporary Literature and Science.* Ithaca: Cornell University Press.

Hayles, N. Katherine, ed. 1991. *Chaos and Order: Complex Dynamics in Literature and Science*. Chicago: University of Chicago Press.

Hayles, N. Katherine. 1992. Gender encoding in fluid mechanics: Masculine channels and feminine flows. *Differences: A Journal of Feminist Cultural Studies* **4**(2): 16–44.

Heinonen, J., T. Kilpeläinen and O. Martio. 1992. Harmonic morphisms in nonlinear potential theory. *Nagoya Mathematical Journal* **125**: 115–140.

Heisenberg, Werner. 1958. *The Physicist's Conception of Nature.* Translated by Arnold J. Pomerans. New York: Harcourt, Brace.

Hirsch, Morris W. 1976. *Differential Topology*. New York: Springer.

Hobsbawm, Eric. 1993. The new threat to history. *New York Review of Books* (16 December): 62–64.

Hochroth, Lysa. 1995. The scientific imperative: Improductive expenditure and energeticism. *Configurations: A Journal of Literature, Science, and Technology* **3**: 47–77.

Honner, John. 1994. Description and deconstruction: Niels Bohr and modern philosophy. In *Niels Bohr and Contemporary Philosophy* (Boston Studies in the Philosophy of Science #153), pp. 141–153, edited by Jan Faye and Henry J. Folse. Dordrecht: Kluwer.

Hughes, Robert. 1993. *Culture of Complaint: The Fraying of America*. New York: Oxford University Press.

Irigaray, Luce. 1985. The 'mechanics' of fluids. In *This Sex Which Is Not One*. Translated by Catherine Porter with Carolyn Burke. Ithaca: Cornell University Press.

Irigaray, Luce. 1987. Le sujet de la science est-il sexué? / Is the subject of science sexed? Translated by Carol Mastrangelo Bové. *Hypatia* **2**(3): 65–87.

Isham, C.J. 1991. Conceptual and geometrical problems in quantum gravity. In *Recent Aspects of Quantum Fields* (Lecture Notes in Physics #396), edited by H. Mitter and H. Gausterer. Berlin: Springer.

Itzykson, Claude and Jean-Bernard Zuber. 1980. *Quantum Field Theory*. New York: McGraw-Hill International.

James, I.M. 1971. Euclidean models of projective spaces. *Bulletin of the London Mathematical Society* **3**: 257–276.

Jameson, Fredric. 1982. Reading Hitchcock. *October* **23**: 15–42.

Jammer, Max. 1974. *The Philosophy of Quantum Mechanics*. New York: Wiley.

Johnson, Barbara. 1977. The frame of reference: Poe, Lacan, Derrida. *Yale French Studies* **55/56**: 457–505.

Johnson, Barbara. 1989. *A World of Difference*. Baltimore: Johns Hopkins University Press.

Jones, V.F.R. 1985. A polynomial invariant for links via Von Neumann algebras. *Bulletin of the American Mathematical Society* **12**: 103–112.

Juranville, Alain. 1984. *Lacan et la Philosophie*. Paris: Presses Universitaires de France.

Kaufmann, Arnold. 1973. *Introduction à la Théorie des Sous-Ensembles Flous à l'Usage des Ingénieurs*. Paris: Masson.

Kazarinoff, N.D. 1985. Pattern formation and morphogenetic fields. In *Mathematical Essays on Growth and the Emergence of Form*, pp. 207–220, edited by Peter L. Antonelli. Edmonton: University of Alberta Press.

Keller, Evelyn Fox. 1985. *Reflections on Gender and Science*. New Haven: Yale University Press.

Keller, Evelyn Fox. 1992. *Secrets of Life, Secrets of Death: Essays on Language, Gender, and Science*. New York: Routledge.

Kitchener, Richard F., ed. 1988. *The World View of Contemporary Physics: Does It Need a New Metaphysics?* Albany, N.Y.: State University of New York Press.

Kontsevich, M. 1994. Résultats rigoureux pour modèles sigma topologiques. Conférence au XI$^{\text{ème}}$ Congrès International de Physique Mathématique, Paris, 18–23 juillet 1994. Edité par Daniel Iagolnitzer et Jacques Toubon. À paraître.

Kosko, Bart. 1993. *Fuzzy Thinking: The New Science of Fuzzy Logic*. New York: Hyperion.

Kosterlitz, J.M. and D.J. Thouless. 1973. Ordering, metastability and phase transitions in two-dimensional systems. *Journal of Physics C* **6**: 1181–1203.

Kroker, Arthur, Marilouise Kroker and David Cook. 1989. *Panic Encyclopedia: The Definitive Guide to the Postmodern Scene*. New York: St. Martin's Press.

Kuhn, Thomas S. 1970. *The Structure of Scientific Revolutions*. 2^{nd} ed. Chicago: University of Chicago Press.

Lacan, Jacques. 1970. Of structure as an inmixing of an otherness prerequisite to any subject whatever. In *The Languages of Criticism and the Sciences of Man*, pp. 186–200, edited by Richard Macksey and Eugenio Donato. Baltimore: Johns Hopkins Press.

Lacan, Jacques. 1977. Desire and the interpretation of desire in *Hamlet*. Translated by James Hulbert. *Yale French Studies* **55/56**: 11–52.

Latour, Bruno. 1987. *Science in Action: How to Follow Scientists and Engineers Through Society*. Cambridge: Harvard University Press.

Latour, Bruno. 1988. A relativistic account of Einstein's relativity. *Social Studies of Science* **18**: 3–44.

Leupin, Alexandre. 1991. Introduction: Voids and knots in knowledge and truth. In *Lacan and the Human Sciences*, pp. 1–23, edited by Alexandre Leupin. Lincoln, Neb.: University of Nebraska Press.

Levin, Margarita. 1988. Caring new world: Feminism and science. *American Scholar* **57**: 100–106.

Lorentz, H.A., A. Einstein, H. Minkowski and H. Weyl. 1952. *The Principle of Relativity*. Translated by W. Perrett and G.B. Jeffery. New York: Dover.

Loxton, J.H., ed. 1990. *Number Theory and Cryptography*. Cambridge–New York: Cambridge University Press.

Lupasco, Stéphane. 1951. *Le Principe d'Antagonisme et la Logique de l'Énergie*. Actualités Scientifiques et Industrielles #1133. Paris: Hermann.

Lyotard, Jean-François. 1989. Time today. Translated by Geoffrey Bennington and Rachel Bowlby. *Oxford Literary Review* **11**: 3–20.

Madsen, Mark and Deborah Madsen. 1990. Structuring postmodern science. *Science and Culture* **56**: 467–472.

Markley, Robert. 1991. What now? An introduction to interphysics. *New Orleans Review* **18**(1): 5–8.

Markley, Robert. 1992. The irrelevance of reality: Science, ideology and the postmodern universe. *Genre* **25**: 249–276.

Markley, Robert. 1994. Boundaries: Mathematics, alienation, and the metaphysics of cyberspace. *Configurations: A Journal of Literature, Science, and Technology* **2**: 485–507.

Martel, Erich. 1991/92. How valid are the Portland baseline essays? *Educational Leadership* **49**(4): 20–23.

Massey, William S. 1978. *Homology and Cohomology Theory*. New York: Marcel Dekker.

Mathews, Freya. 1991. *The Ecological Self*. London: Routledge.

Maudlin, Tim. 1994. *Quantum Non-Locality and Relativity: Metaphysical Intimations of Modern Physics*. Aristotelian Society Series, vol. 13. Oxford: Blackwell.

McAvity, D.M. and H. Osborn. 1991. A DeWitt expansion of the heat kernel for manifolds with a boundary. *Classical and Quantum Gravity* **8**: 603–638.

McCarthy, Paul. 1992. Postmodern pleasure and perversity: Scientism and sadism. *Postmodern Culture* **2**, no. 3. Available as `mccarthy.592` from `listserv@listserv.ncsu.edu` or `http://jefferson.village.virginia.edu/pmc` (Internet). Also reprinted in *Essays in Postmodern Culture*, pp. 99–132, edited by Eyal Amiran and John Unsworth. New York: Oxford University Press, 1993.

Merchant, Carolyn. 1980. *The Death of Nature: Women, Ecology, and the Scientific Revolution*. New York: Harper & Row.

Merchant, Carolyn. 1992. *Radical Ecology: The Search for a Livable World*. New York: Routledge.

Mermin, N. David. 1990. Quantum mysteries revisited. *American Journal of Physics* **58**: 731–734.

Mermin, N. David. 1993. Hidden variables and the two theorems of John Bell. *Reviews of Modern Physics* **65**: 803–815.

Merz, Martina and Karin Knorr Cetina. 1994. Deconstruction in a 'thinking' science: Theoretical physicists at work. Geneva: European Laboratory for Particle Physics (CERN), preprint CERN-TH.7152/94.

Miller, Jacques-Alain. 1977/78. Suture (elements of the logic of the signifier). *Screen* **18**(4): 24–34.

Morin, Edgar. 1992. *The Nature of Nature* (Method: Towards a Study of Humankind, vol. 1). Translated by J.L. Roland Bélanger. New York: Peter Lang.

Morris, David B. 1988. Bootstrap theory: Pope, physics, and interpretation. *The Eighteenth Century: Theory and Interpretation* **29**: 101–121.

Munkres, James R. 1984. *Elements of Algebraic Topology*. Menlo Park, Calif.: Addison-Wesley.

Nabutosky, A. and R. Ben-Av. 1993. Noncomputability arising in dynamical triangulation model of four-dimensional quantum gravity. *Communications in Mathematical Physics* **157**: 93–98.

Nandy, Ashis, ed. 1990. *Science, Hegemony and Violence: A Requiem for Modernity*. Delhi: Oxford University Press.

Nash, Charles and Siddhartha Sen. 1983. *Topology and Geometry for Physicists*. London: Academic Press.

Nasio, Juan-David. 1987. *Les Yeux de Laure: Le Concept d'Objet a dans la Théorie de J. Lacan. Suivi d'une Introduction à la Topologie Psychanalytique*. Paris: Aubier.

Nasio, Juan-David. 1992. Le concept de sujet de l'inconscient. Texte d'une intervention realisée dans le cadre du séminaire de Jacques Lacan "La topologie et le temps", le mardi 15 mai 1979. In *Cinq Lecons sur la Théorie de Jacques Lacan*. Paris: Éditions Rivages.

Nye, Andrea. 1990. *Words of Power: A Feminist Reading of the History of Logic*. New York: Routledge.

Oliver, Kelly. 1989. Keller's gender/science system: Is the philosophy of science to science as science is to nature? *Hypatia* **3**(3): 137–148.

Ortiz de Montellano, Bernard. 1991. Multicultural pseudoscience: Spreading scientific illiteracy among minorities: Part I. *Skeptical Inquirer* **16**(2): 46–50.

Overstreet, David. 1980. Oxymoronic language and logic in quantum mechanics and James Joyce. *Sub-Stance* **28**: 37–59.

Pais, Abraham. 1991. *Niels Bohr's Times: In Physics, Philosophy, and Polity*. New York: Oxford University Press.

Patai, Daphne and Noretta Koertge. 1994. *Professing Feminism: Cautionary Tales from the Strange World of Women's Studies*. New York: Basic Books.

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

Plotnitsky, Arkady. 1994. *Complementarity: Anti-Epistemology after Bohr and Derrida*. Durham, N.C.: Duke University Press.

Plumwood, Val. 1993a. *Feminism and the Mastery of Nature*. London: Routledge.

Plumwood, Val. 1993b. The politics of reason: Towards a feminist logic. *Australasian Journal of Philosophy* **71**: 436–462.

Porter, Jeffrey. 1990. "Three quarks for Muster Mark": Quantum wordplay and nuclear discourse in Russell Hoban's *Riddley Walker*. *Contemporary Literature* **21**: 448–469.

Porush, David. 1989. Cybernetic fiction and postmodern science. *New Literary History* **20**: 373–396.

Porush, David. 1993. Voyage to Eudoxia: The emergence of a post-rational epistemology in literature and science. *SubStance* **71/72**: 38–49.

Prigogine, Ilya and Isabelle Stengers. 1984. *Order out of Chaos: Man's New Dialogue with Nature*. New York: Bantam.

Primack, Joel R. and Nancy Ellen Abrams. 1995. "In a beginning ...": Quantum cosmology and Kabbalah. *Tikkun* **10**(1) (January/February): 66–73.

Psarev, V.I. 1990. Morphogenesis of distributions of microparticles by dimensions in the coarsening of dispersed systems. *Soviet Physics Journal* **33**: 1028–1033.

Ragland-Sullivan, Ellie. 1990. Counting from 0 to 6: Lacan, "suture", and the imaginary order. In *Criticism and Lacan: Essays and Dialogue on Language, Structure, and the Unconscious*, pp. 31–63, edited by Patrick Colm Hogan and Lalita Pandit. Athens, Ga.: University of Georgia Press.

Rensing, Ludger, ed. 1993. Oscillatory signals in morphogenetic fields. Part II of *Oscillations and Morphogenesis*, pp. 133–209. New York: Marcel Dekker.

Rosenberg, Martin E. 1993. Dynamic and thermodynamic tropes of the subject in Freud and in Deleuze and Guattari. *Postmodern Culture* **4**, no. 1. Available as `rosenber.993` from `listserv@listserv.ncsu.edu` or `http://jefferson.village.virginia.edu/pmc` (Internet).

Ross, Andrew. 1991. *Strange Weather: Culture, Science, and Technology in the Age of Limits*. London: Verso.

Ross, Andrew. 1994. *The Chicago Gangster Theory of Life: Nature's Debt to Society*. London: Verso.

Saludes i Closa, Jordi. 1984. Un programa per a calcular l'homologia simplicial. *Butlletí de la Societat Catalana de Ciències* (segona època) **3**: 127–146.

Santos, Boaventura de Sousa. 1989. *Introdução a uma Ciência Pós-Moderna*. Porto: Edições Afrontamento.

Santos, Boaventura de Sousa. 1992. A discourse on the sciences. *Review (Fernand Braudel Center)* **15**(1): 9–47.

Sardar, Ziauddin, ed. 1988. *The Revenge of Athena: Science, Exploitation and the Third World*. London: Mansell.

Schiffmann, Yoram. 1989. The second messenger system as the morphogenetic field. *Biochemical and Biophysical Research Communications* **165**: 1267–1271.

Schor, Naomi. 1989. This essentialism which is not one: Coming to grips with Irigaray. *Differences: A Journal of Feminist Cultural Studies* **1**(2): 38–58.

Schubert, G. 1989. Catastrophe theory, evolutionary extinction, and revolutionary politics. *Journal of Social and Biological Structures* **12**: 259–279.

Schwartz, Laurent. 1973. *Radon Measures on Arbitrary Topological Spaces and Cylindrical Measures*. London: Oxford University Press.

Seguin, Eve. 1994. A modest reason. *Theory, Culture & Society* **11**(3): 55–75.

Serres, Michel. 1992. *Éclaircissements: Cinq Entretiens avec Bruno Latour*. Paris: François Bourin.

Sheldrake, Rupert. 1981. *A New Science of Life: The Hypothesis of Formative Causation*. Los Angeles: J.P. Tarcher.

Sheldrake, Rupert. 1991. *The Rebirth of Nature*. New York: Bantam.

Shiva, Vandana. 1990. Reductionist science as epistemological violence. In *Science, Hegemony and Violence: A Requiem for Modernity*, pp. 232–256, edited by Ashis Nandy. Delhi: Oxford University Press.

Smolin, Lee. 1992. Recent developments in nonperturbative quantum gravity. In *Quantum Gravity and Cosmology* (Proceedings 1991, Sant Feliu de Guixols,

Estat Lliure de Catalunya), pp. 3–84, edited by J. Pérez-Mercader, J. Sola and E. Verdaguer. Singapore: World Scientific.

Sokal, Alan D. 1982. An alternate constructive approach to the φ_3^4 quantum field theory, and a possible destructive approach to φ_4^4. *Annales de l'Institut Henri Poincaré A* **37**: 317–398.

Sokal, Alan. 1987. Informe sobre el plan de estudios de las carreras de Matemática, Estadística y Computación. Report to the Universidad Nacional Autónoma de Nicaragua, Managua, unpublished.

Solomon, J. Fisher. 1988. *Discourse and Reference in the Nuclear Age*. Oklahoma Project for Discourse and Theory, vol. 2. Norman: University of Oklahoma Press.

Sommers, Christina Hoff. 1994. *Who Stole Feminism?: How Women Have Betrayed Women*. New York: Simon & Schuster.

Stauffer, Dietrich. 1985. *Introduction to Percolation Theory*. London: Taylor & Francis.

Strathausen, Carsten. 1994. Althusser's mirror. *Studies in 20th Century Literature* **18**: 61–73.

Struik, Dirk Jan. 1987. *A Concise History of Mathematics*. 4^{th} rev. ed. New York: Dover.

Thom, René. 1975. *Structural Stability and Morphogenesis*. Translated by D.H. Fowler. Reading, Mass.: Benjamin.

Thom, René. 1990. *Semio Physics: A Sketch*. Translated by Vendla Meyer. Redwood City, Calif.: Addison-Wesley.

't Hooft, G. 1993. Cosmology in 2+1 dimensions. *Nuclear Physics B (Proceedings Supplement)* **30**: 200–203.

Touraine, Alain, Zsuzsa Hegedus, François Dubet and Michel Wievorka. 1980. *La Prophétie Anti-Nucléaire*. Paris: Éditions du Seuil.

Trebilcot, Joyce. 1988. Dyke methods, or Principles for the discovery/creation of the withstanding. *Hypatia* **3**(2): 1–13.

Van Enter, Aernout C.D., Roberto Fernández and Alan D. Sokal. 1993. Regularity properties and pathologies of position-space renormalization-group transformations: Scope and limitations of Gibbsian theory. *Journal of Statistical Physics* **72**: 879–1167.

Van Sertima, Ivan, ed. 1983. *Blacks in Science: Ancient and Modern*. New Brunswick, N.J.: Transaction Books.

Vappereau, Jean Michel. 1985. *Essaim: Le Groupe Fondamental du Noeud*. Psychanalyse et Topologie du Sujet. Paris: Point Hors Ligne.

Virilio, Paul. 1991. *The Lost Dimension*. Translation of *L'espace critique*. Translated by Daniel Moshenberg. New York: Semiotext(e).

Waddington, C.H. 1965. Autogenous cellular periodicities as (a) temporal templates and (b) basis of 'morphogenetic fields'. *Journal of Theoretical Biology* **8**: 367–369.

Wallerstein, Immanuel. 1993. The TimeSpace of world-systems analysis: A philosophical essay. *Historical Geography* **23**(1/2): 5–22.

Weil, Simone. 1968. *On Science, Necessity, and the Love of God.* Translated and edited by Richard Rees. London: Oxford University Press.

Weinberg, Steven. 1992. *Dreams of a Final Theory.* New York: Pantheon.

Wheeler, John A. 1964. Geometrodynamics and the issue of the final state. In *Relativity, Groups and Topology*, edited by Cécile M. DeWitt and Bryce S. DeWitt. New York: Gordon and Breach.

Witten, Edward. 1989. Quantum field theory and the Jones polynomial. *Communications in Mathematical Physics* **121**: 351–399.

Wojciehowski, Dolora Ann. 1991. Galileo's two chief word systems. *Stanford Italian Review* **10**: 61–80.

Woolgar, Steve. 1988. *Science: The Very Idea.* Chichester, England: Ellis Horwood.

Wright, Will. 1992. *Wild Knowledge: Science, Language, and Social Life in a Fragile Environment.* Minneapolis: University of Minnesota Press.

Wylie, Alison, Kathleen Okruhlik, Sandra Morton and Leslie Thielen-Wilson. 1990. Philosophical feminism: A bibliographic guide to critiques of science. *Resources for Feminist Research/Documentation sur la Recherche Féministe* **19**(2) (June): 2–36.

Young, T.R. 1991. Chaos theory and symbolic interaction theory: Poetics for the postmodern sociologist. *Symbolic Interaction* **14**: 321–334.

Young, T.R. 1992. Chaos theory and human agency: Humanist sociology in a postmodern era. *Humanity & Society* **16**: 441–460.

Žižek, Slavoj. 1991. *Looking Awry: An Introduction to Jacques Lacan through Popular Culture.* Cambridge, Mass.: MIT Press.