Transgressing the Boundaries: Towards a Transformative Hermeneutics of Quantum Gravity

Alan D. Sokal
Department of Physics
New York University
4 Washington Place
New York, NY 10003 USA

Internet: `SOKAL@NYU.EDU`
Telephone: (212) 998-7729
Fax: (212) 995-4016

November 28, 1994
revised May 13, 1995
Typeset in LaTeX

Biographical Information

The author is a Professor of Physics at New York University. He has lectured widely in Europe and Latin America, including at the Università di Roma "La Sapienza" and, during the Sandinista government, at the Universidad Nacional Autónoma de Nicaragua. He is co-author with Roberto Fernández and Jürg Fröhlich of *Random Walks, Critical Phenomena, and Triviality in Quantum Field Theory* (Springer, 1992).

> 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 Ross' discussion of oppositional discourses 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).

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 space-time 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 ...
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> 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*

[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).

> *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 Heisenberg,

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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:

> 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 reevaluation

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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 space-time (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).

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 time

[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).

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

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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.

find them so difficult to solve.[33] Newton's gravitational theory corresponds to the 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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[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] 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 non-commuting (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.

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

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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.

[41]Luce Irigaray (1987, 77–78) has pointed out that the contradictions between quantum theory and

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 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

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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).

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 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

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, 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

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 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 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 homol-

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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).

[65]Witten (1989).

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

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[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.

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.

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

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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.

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, quantum gravity again qualifies: in the passage from classical general relativity to the

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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, 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 dif-

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, 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

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> ferences 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).

[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

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]

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

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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.

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 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

[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.

> 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 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

[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).

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

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 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

[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.

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

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

[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).

has, since Galileo, been formulated in the language of mathematics.[100,101] But *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

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[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]

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)

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] 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

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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):

> 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).

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.

I wish to thank Giacomo Caracciolo, Lucía Fernández-Santoro, Lia Gutiérrez and Elizabeth Meiklejohn for enjoyable discussions which have contributed greatly to this article. Needless to say, these people should not be assumed to be in total agreement with the scientific and political views expressed here, nor are they responsible for any errors or obscurities which may inadvertently remain.

Afterword (Submitted to *Social Text*)

> I did not write this work merely with the aim of setting the exegetical record straight. My larger target is those contemporaries who — in repeated acts of wish-fulfillment — have appropriated conclusions from the philosophy of science and put them to work in aid of a variety of social cum political causes for which those conclusions are ill adapted. Feminists, religious apologists (including "creation scientists"), counterculturalists, neoconservatives, and a host of other curious fellow-travelers have claimed to find crucial grist for their mills in, for instance, the avowed incommensurability and underdetermination of scientific theories. The displacement of the idea that facts and evidence matter by the idea that everything boils down to subjective interests and perspectives is — second only to American political campaigns — the most prominent and pernicious manifestation of anti-intellectualism in our time.
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> — *Larry Laudan, Science and Relativism (1990, p. x)*

[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).

Les grandes personnes sont décidément bien bizarres, se dit le petit prince.

— *Antoine de Saint Exupéry, Le Petit Prince*

Alas, the editors of *Social Text* have discovered that my article, "Transgressing the Boundaries: Toward a Transformative Hermeneutics of Quantum Gravity", which appeared in *Social Text* #46/47, is a parody. In view of the important intellectual and political issues raised by this episode, they have generously agreed to publish this (non-parodic) Afterword, in which I explain my motives and my true views.[110] One of my goals is to make a small contribution toward a dialogue on the Left between humanists and natural scientists — "two cultures" which, contrary to some optimistic pronouncements (mostly by the former group), are probably farther apart in mentality than at any time in the past 50 years.

Like the genre it is meant to satirize — myriad exemplars of which can be found in my reference list — my article is a mélange of truths, half-truths, quarter-truths, falsehoods, non sequiturs, and syntactically correct sentences that have no meaning whatsoever. (Sadly, there are only a handful of the latter: I tried hard to produce them, but I found that, save for rare bursts of inspiration, I just didn't have the knack.) I also employed some other strategies that are well-established (albeit sometimes inadvertently) in the genre: appeals to authority in lieu of logic; speculative theories passed off as established science; strained and even absurd analogies; rhetoric that sounds good but whose meaning is ambiguous; and confusion between the technical and everyday senses of English words.[111] (N.B. All works cited in my article are real, and all quotations are rigorously accurate; none are invented.)

But why did I do it? I confess that I'm an unabashed Old Leftist who never quite understood how deconstruction was supposed to help the working class. And I'm a stodgy old scientist who believes, naively, that there exists an external world, that there exist objective truths about that world, and that my job is to discover some of them. (If science were merely a negotiation of social conventions about what is agreed to be "true", why would I bother devoting a large fraction of my all-too-short life to it? I don't aspire to be the Emily Post of quantum field theory.[112])

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[110] Readers are cautioned not to infer my views on any subject except insofar as they are set forth in this Afterword. In particular, the fact that I have parodied an extreme or ambiguously stated version of an idea does not exclude that I may agree with a more nuanced or precisely stated version of the same idea.

[111] For example: "linear", "nonlinear", "local", "global", "multidimensional", "relative", "frame of reference", "field", "anomaly", "chaos", "catastrophe", "logic", "irrational", "imaginary", "complex", "real", "equality", "choice".

[112] By the way, anyone who believes that the laws of physics are mere social conventions is invited to try transgressing those conventions from the windows of my apartment. I live on the twenty-first floor. (P.S. I am aware that this wisecrack is unfair to the more sophisticated relativist philosophers of science, who will concede that *empirical statements* can be objectively true — e.g. the fall from my window to the pavement will take approximately 2.5 seconds — but claim that the *theoretical*

But my main concern isn't to defend science from the barbarian hordes of lit crit (we'll survive just fine, thank you). Rather, my concern is explicitly *political*: to combat a currently fashionable postmodernist/poststructuralist/social-constructivist discourse — and more generally a penchant for subjectivism — which is, I believe, inimical to the values and future of the Left.[113] Alan Ryan said it well:

> It is, for instance, pretty suicidal for embattled minorities to embrace Michel Foucault, let alone Jacques Derrida. The minority view was always that power could be undermined by truth ... Once you read Foucault as saying that truth is simply an effect of power, you've had it. ... But American departments of literature, history and sociology contain large numbers of self-described leftists who have confused radical doubts about objectivity with political radicalism, and are in a mess.[114]

Likewise, Eric Hobsbawm has decried

> the rise of "postmodernist" intellectual fashions in Western universities, particularly in departments of literature and anthropology, which imply that all "facts" claiming objective existence are simply intellectual constructions. In short, that there is no clear difference between fact and fiction. But there is, and for historians, even for the most militantly antipositivist ones among us, the ability to distinguish between the two is absolutely fundamental.[115]

(Hobsbawm goes on to show how rigorous historical work can refute the fictions propounded by reactionary nationalists in India, Israel, the Balkans and elsewhere.) And finally Stanislav Andreski:

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explanations of those empirical statements are more-or-less arbitrary social constructions. I think that also this view is largely wrong, but that is a much longer discussion.)

[113]The natural sciences have little to fear, at least in the short run, from postmodernist silliness; it is, above all, history and the social sciences — and leftist politics — that suffer when verbal game-playing displaces the rigorous analysis of social realities. Nevertheless, because of the limitations of my own expertise, my analysis here will be restricted to the natural sciences (and indeed primarily to the physical sciences). While the basic epistemology of inquiry ought to be roughly the same for the natural and social sciences, I am of course perfectly aware that many special (and very difficult) methodological issues arise in the social sciences from the fact that the objects of inquiry are human beings (including their subjective states of mind); that these objects of inquiry have intentions (including in some cases the concealment of evidence or the placement of deliberately self-serving evidence); that the evidence is expressed (usually) in human language whose meaning may be ambiguous; that the meaning of conceptual categories (e.g. childhood, masculinity, femininity, family, economics, etc.) changes over time; that the goal of historical inquiry is not just facts but interpretation, etc. So by no means do I claim that my comments about physics should apply directly to history and the social sciences — that would be absurd. To say that "physical reality is a social and linguistic construct" is just plain silly, but to say that "social reality is a social and linguistic construct" is virtually a tautology.

[114]Ryan (1992).

[115]Hobsbawm (1993, 63).

> So long as authority inspires awe, confusion and absurdity enhance conservative tendencies in society. Firstly, because clear and logical thinking leads to a cumulation of knowledge (of which the progress of the natural sciences provides the best example) and the advance of knowledge sooner or later undermines the traditional order. Confused thinking, on the other hand, leads nowhere in particular and can be indulged indefinitely without producing any impact upon the world.[116]

As an example of "confused thinking", I would like to consider a chapter from Harding (1991) entitled "Why 'Physics' Is a Bad Model for Physics". I select this example both because of Harding's prestige in certain (but by no means all) feminist circles, and because her essay is (unlike much of this genre) very clearly written. Harding wishes to answer the question, "Are feminist criticisms of Western thought relevant to the natural sciences?" She does so by raising, and then rebutting, six "false beliefs" about the nature of science. Some of her rebuttals are perfectly well-taken; but they don't prove anything like what she claims they do. That is because she confutes five quite distinct issues:

1) *Ontology.* What objects *exist* in the world? What statements about these objects are *true*?

2) *Epistemology.* How can human beings obtain *knowledge* of truths about the world? How can they assess the *reliability* of that knowledge?

3) *Sociology of knowledge.* To what extent are the truths *known* (or *knowable*) by humans in any given society influenced (or determined) by social, economic, political, cultural and ideological factors? Same question for the false statements erroneously believed to be true.

4) *Individual ethics.* What types of research *ought* a scientist (or technologist) to undertake (or refuse to undertake)?

5) *Social ethics.* What types of research *ought* society to encourage, subsidize or publicly fund (or alternatively to discourage, tax or forbid)?

These questions are obviously related — e.g. if there are no objective truths about the world, then there isn't much point in asking how one can know those (nonexistent) truths — but they are conceptually distinct.

For example, Harding (citing Forman 1987) points out that American research in the 1940s and 50s on quantum electronics was motivated in large part by potential military applications. True enough. Now, quantum mechanics made possible solid-state physics, which in turn made possible quantum electronics (e.g. the transistor), which made possible nearly all of modern technology (e.g. the computer).[117]

[116] Andreski (1972, 90).

[117] Computers existed prior to solid-state technology, but they were unwieldy and slow. The 486 PC sitting today on the literary theorist's desk is roughly 1000 times more powerful than the room-sized vacuum-tube computer IBM 704 from 1954 (see e.g. Williams 1985).

And the computer has had applications that are beneficial to society (e.g. in allowing the postmodern cultural critic to produce her articles more efficiently) as well as applications that are harmful (e.g. in allowing the U.S. military to kill human beings more efficiently). This raises a host of social and individual ethical questions: Ought society to forbid (or discourage) certain applications of computers? Forbid (or discourage) research on computers *per se*? Forbid (or discourage) research on quantum electronics? On solid-state physics? On quantum mechanics? And likewise for individual scientists and technologists. (Clearly, an affirmative answer to these questions becomes harder to justify as one goes down the list; but I do not want to declare any of these questions *a priori* illegitimate.) Likewise, sociological questions arise, for example: To what extent is our (true) knowledge of computer science, quantum electronics, solid-state physics and quantum mechanics — and our lack of knowledge about other scientific subjects, e.g. the global climate — a result of public-policy choices favoring militarism? To what extent have the erroneous theories (if any) in computer science, quantum electronics, solid-state physics and quantum mechanics been the result (in whole or in part) of social, economic, political, cultural and ideological factors, in particular the culture of militarism?[118] These are all serious questions, which deserve careful investigation adhering to the highest standards of scientific and historical evidence. *But they have no effect whatsoever on the underlying scientific questions:* whether atoms (and silicon crystals, transistors and computers) really do behave according to the laws of quantum mechanics (and solid-state physics, quantum electronics and computer science). The militaristic orientation of American science has quite simply no bearing whatsoever on the ontological question, and only under a wildly implausible scenario could it have any bearing on the epistemological question. (E.g. if the worldwide community of solid-state physicists, following what they believe to be the conventional standards of scientific evidence, were to hastily accept an erroneous theory of semiconductor behavior because of their enthusiasm for the breakthrough in military technology that this theory would make possible.)

Andrew Ross has drawn an analogy between the hierarchical taste cultures (high, middlebrow and popular) familiar to cultural critics, and the demarcation between science and pseudoscience.[119] At a sociological level this is an incisive observation; but at an ontological and epistemological level it is simply mad. Ross seems to recognize this, because he immediately says:

> I do not want to insist on a literal interpretation of this analogy ... A more exhaustive treatment would take account of the local, qualifying differences between the realm of cultural taste and that of science [!], but it would run up,

[118] I certainly don't exclude the possibility that *present* theories in any of these subjects might be erroneous. But critics wishing to make such a case would have to provide not only historical evidence of the claimed cultural influence, but also *scientific* evidence that the theory in question is in fact erroneous. (The same evidentiary standards of course apply to *past* erroneous theories; but in this case the scientists may have already performed the second task, relieving the cultural critic of the need to do so from scratch.)

[119] Ross (1991, 25–26); also in Ross (1992, 535–536).

> finally, against the stand-off between the empiricist's claim that non-context-dependent beliefs exist and that they can be true, and the culturalist's claim that beliefs are only socially accepted as true.[120]

But such epistemological agnosticism simply won't suffice, at least not for people who aspire to make social change. Deny that non-context-dependent assertions can be true, and you don't just throw out quantum mechanics and molecular biology: you also throw out the Nazi gas chambers, the American enslavement of Africans, and the fact that today in New York it's raining. Hobsbawm is right: facts do matter, and some facts (like the first two cited here) matter a great deal.

Still, Ross is correct that, at a sociological level, maintaining the demarcation line between science and pseudoscience serves — *among other things* — to maintain the social power of those who, whether or not they have formal scientific credentials, stand on science's side of the line. (It has *also* served to increase the mean life expectancy in the United States from 47 years to 76 years in less than a century.[121]) Ross notes that

> Cultural critics have, for some time now, been faced with the task of exposing similar vested institutional interests in the debates about class, gender, race, and sexual preference that touch upon the demarcations between taste cultures, and I see no ultimate reason for us to abandon our hard-earned skepticism when we confront science.[122]

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[120] Ross (1991, 26); also in Ross (1992, 535). In the discussion following this paper, Ross (1992, 549) expressed further (and quite justified) misgivings:

> I'm quite skeptical of the "anything goes" spirit that is often the prevailing climate of relativism around postmodernism. ... Much of the postmodernist debate has been devoted to grappling with the philosophical or cultural limits to the grand narratives of the Enlightenment. If you think about ecological questions in this light, however, then you are talking about "real" physical, or material, limits to our resources for encouraging social growth. And postmodernism, as we know, has been loath to address the "real," except to announce its banishment.

[121] U.S. Bureau of the Census (1975, 47, 55; 1994, 87). In 1900 the mean life expectancy at birth was 47.3 years (47.6 years for whites, and a shocking 33.0 years for "Negro and other"). In 1995 it is 76.3 years (77.0 years for whites, 70.3 years for blacks).

I am aware that this assertion is likely to be misinterpreted, so let me engage in some pre-emptive clarification. I am *not* claiming that all of the increase in life expectancy is due to advances in scientific *medicine*. A large fraction (possibly the dominant part) of the increase — especially in the first three decades of the twentieth century — is due to the general improvement in the standards of housing, nutrition and public sanitation (the latter two informed by improved scientific understanding of the etiology of infectious and dietary-deficiency diseases). [For reviews of the evidence, see e.g. Holland *et al.* (1991).] But — without discounting the role of social struggles in these improvements, particularly as concerns the narrowing of the racial gap — the underlying and overwhelming cause of these improvements is quite obviously the vast increase in the material standard of living over the past century, by more than a factor of five (U.S. Bureau of the Census 1975, 224–225; 1994, 451). And this increase is quite obviously the direct result of science, as embodied in technology.

[122] Ross (1991, 26); also in Ross (1992, 536).

Fair enough: scientists are in fact the *first* to advise skepticism in the face of other people's (and one's own) truth claims. But a sophomoric skepticism, a bland (or blind) agnosticism, won't get you anywhere. Cultural critics, like historians or scientists, need an *informed* skepticism: one that can evaluate evidence and logic, and come to reasoned (albeit tentative) judgments *based on that evidence and logic.*

At this point Ross may object that I am rigging the power game in my own favor: how is he, a professor of American Studies, to compete with me, a physicist, in a discussion of quantum mechanics?[123] (Or even of nuclear power — a subject on which I have no expertise whatsoever.) But it is equally true that I would be unlikely to win a debate with a professional historian on the causes of World War I. Nevertheless, as an intelligent lay person with a modest knowledge of history, I am capable of evaluating the evidence and logic offered by competing historians, and of coming to some sort of reasoned (albeit tentative) judgment. (Without that ability, how could any thoughtful person justify being politically active?)

The trouble is that few non-scientists in our society feel this self-confidence when dealing with scientific matters. As C.P. Snow observed in his famous "Two Cultures" lecture 35 years ago:

> A good many times I have been present at gatherings of people who, by the standards of the traditional culture, are thought highly educated and who have with considerable gusto been expressing their incredulity at the illiteracy of scientists. Once or twice I have been provoked and have asked the company how many of them could describe the Second Law of Thermodynamics. The response was cold: it was also negative. Yet I was asking something which is about the scientific equivalent of: *Have you read a work of Shakespeare's?*
>
> I now believe that if I had asked an even simpler question — such as, What do you mean by mass, or acceleration, which is the scientific equivalent of saying, *Can you read?* — not more than one in ten of the highly educated would have felt that I was speaking the same language. So the great edifice of modern physics goes up, and the majority of the cleverest people in the western world have about as much insight into it as their neolithic ancestors would have had.[124]

[123]By the way, intelligent non-scientists seriously interested in the conceptual problems raised by quantum mechanics need no longer rely on the vulgarizations (in both senses) published by Heisenberg, Bohr and sundry physicists and New Age authors. The little book of Albert (1992) provides an impressively serious and *intellectually honest* account of quantum mechanics and the philosophical issues it raises — yet it requires no more mathematical background than a modicum of high-school algebra, and does not require any prior knowledge of physics. The main requirement is a willingness to think *slowly* and *clearly*.

[124]Snow (1963, 20–21). One significant change has taken place since C.P. Snow's time: while humanist intellectuals' ignorance about (for example) mass and acceleration remains substantially unchanged, nowadays a significant minority of humanist intellectuals feels entitled to pontificate on these subjects in spite of their ignorance (perhaps trusting that their readers will be equally ignorant). Consider, for example, the following excerpt from a recent book on *Rethinking Technologies*, edited by the Miami Theory Collective and published by the University of Minnesota Press: "it now seems appropriate to reconsider the notions of acceleration and deceleration (what physicists call positive

A lot of the blame for this state of affairs rests, I think, with the scientists. The teaching of mathematics and science *is* often authoritarian[125]; and this is antithetical not only to the principles of radical/democratic pedagogy but to the principles of science itself. No wonder most Americans can't distinguish between science and pseudoscience: their science teachers have never given them any rational grounds for doing so. (Ask an average undergraduate: Is matter composed of atoms? Yes. Why do you think so? The reader can fill in the response.) Is it then any surprise that 36% of Americans believe in telepathy, and that 47% believe in the creation account of Genesis?[126]

As Ross has noted[127], many of the central political issues of the coming decades — from health care to global warming to Third World development — depend in part on subtle (and hotly debated) questions of scientific fact. But they don't depend only on scientific fact: they depend also on ethical values and — in this journal it hardly needs to be added — on naked economic interests. No Left can be effective unless it takes seriously questions of scientific fact *and* of ethical values *and* of economic interests. The issues at stake are too important to be left to the capitalists or to the scientists — or to the postmodernists.

A quarter-century ago, at the height of the U.S. invasion of Vietnam, Noam Chomsky observed that:

> George Orwell once remarked that political thought, especially on the left, is a sort of masturbation fantasy in which the world of fact hardly matters. That's

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and negative speeds)" (Virilio 1993, 5). The reader who does not find this uproariously funny (as well as depressing) is invited to sit in on the first two weeks of Physics I.

[125] I wasn't joking about that. For anyone who is interested in my views, I would be glad to provide a copy of Sokal (1987). For another sharp critique of the poor teaching of mathematics and science, see (irony of ironies) Gross and Levitt (1994b, 23–28).

[126] Telepathy: Hastings and Hastings (1992, 518), American Institute of Public Opinion poll from June 1990. Concerning "telepathy, or communication between minds without using the traditional five senses", 36% "believe in", 25% are "not sure", and 39% "do not believe in". For "people on this earth are sometimes possessed by the devil", it is 49–16–35 (!). For "astrology, or that the position of the stars and planets can affect people's lives", it is 25–22–53. Mercifully, only 11% believe in channeling (22% are not sure), and 7% in the healing power of pyramids (26% not sure).

Creationism: Gallup (1993, 157–159), Gallup poll from June 1993. The exact question was: "Which of the following statements comes closest to your views on the origin and development of human beings: 1) human beings have developed over millions of years from less advanced forms of life, but God guided this process; 2) human beings have developed over millions of years from less advanced forms of life, but God had no part in this process; 3) God created human beings pretty much in their present form at one time within the last 10,000 years or so?" The results were 35% developed with God, 11% developed without God, 47% God created in present form, 7% no opinion. A poll from July 1982 (Gallup 1982, 208–214) found almost identical figures, but gave breakdowns by sex, race, education, region, age, income, religion, and community size. Differences by sex, race, region, income and (surprisingly) religion were rather small. By far the largest difference was by education: only 24% of college graduates supported creationism, compared to 49% of high-school graduates and 52% of those with a grade-school education. So maybe the worst science teaching is at the elementary and secondary levels.

[127] See Note 120 above.

> true, unfortunately, and it's part of the reason that our society lacks a genuine, responsible, serious left-wing movement.[128]

Perhaps that's unduly harsh, but there's unfortunately a significant kernel of truth in it. Nowadays the erotic text tends to be written in (broken) French rather than Chinese, but the real-life consequences remain the same. Here's Alan Ryan in 1992, concluding his wry analysis of American intellectual fashions with a lament that

> the number of people who combine intellectual toughness with even a modest political radicalism is pitifully small. Which, in a country that has George Bush as President and Danforth Quayle lined up for 1996, is not very funny.[129]

Four years later, with Bill Clinton installed as our supposedly "progressive" president and Newt Gingrich already preparing for the new millennium, it still isn't funny.

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[128] Chomsky (1984, 200), lecture delivered in 1969.

[129] Ryan (1992).

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