Nonlinear Science and the Postpositivist Researcher

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This essay discusses the relationship of postpositivist research and nonlinear science, particularly in terms of their importance to the educational researcher. It is frequently said that we are in a time of shifting paradigms, perhaps even a "postparadigmatic diaspora." For at least the last few hundred years, the dominant Western paradigm has been grounded in the principals of linear science resulting in both amazing technological invention and widespread human suffering. Postpositivist researchers have been among those attempting to explore alternatives to this paradigm in the hopes of creating a better world, even when questioning the very idea of progress. Such researchers have both challenged and extended the notion of science.

In recent times, as postpositivism has gained ground, a paradigm shift has begun in the traditional, hard or linear sciences. This shift offers useful concepts for the postpositivist researcher both for critiques of linear science and for the development of postpositivist theory and practice. Since the linear scientific worldview has dominated educational research, shifts in that worldview will likely have a great impact on research in education. Furthermore, since postpositivism defines itself in relationship to that worldview, the postpositivist educational researcher must, at the very least, consider how this paradigm shift is unfolding, what ideas are being explored by nonlinear scientists and how the postpositivist researcher can be instrumental in the reception of these ideas in the field of education rather than simply responding at a later date.

A Cautionary Note

In this essay I deploy certain terms and citations in order to present ideas regarding major challenges to still dominant perceptions of knowledge and science. Many of the terms are used differently by different scholars and so I attempt to be clear about how I use them with the awareness that naming is a power play in the language game of academic writing. While my use of terminology will perhaps clarify the rules of the game I am playing, my use of citations may not be as clear.

Like any good bricoleur, I will juxtapose statements by individuals from diverse disciplinary and postdisciplinary traditions in order to say things they may not intend. Such a maneuver is a way of making their work "groan and protest" (Foucault, 1980, pp. 53-54) by exceeding their intended meaning. In addition I will be discussing scientific discourse using the words of scientists from both the physical and human sciences as well as science journalists, nonscientists and antiscientists, without clearly delineating any separation. I follow Emily Martin's (1996) observation that "scientific knowledge is being made by all of us; we all move in and out of the bustling city of knowledge production (p. 102). In doing so, I am attempting to bootstrap across diverse theoretical terrain and ontological/epistemological perspectives.

In any case, the reader should be reminded that no textual staging is innocent and that all knowledge is partial, especially when making such large claims and covering as wide a territory as does this essay. Furthermore, my use of various terms, such as positivism, is almost always a broad stroke meant to gesture toward diverse theoretical terrain with related characteristics. Generally such terrain shifts over time varying from location to location. Such a shorthand is necessary for this sort of essay yet is not intended to create reified categories out of heterogeneous pursuits. The first term to be given such treatment is "nonlinear science."

Chaos, Complexity & Catastrophe

Nonlinear science (sometimes the nonlinear sciences) is a catchall term for theories of chaos, complexity, catastrophe and related nonlinear phenomenon. The emergence of these endeavors has been most widely marked with the publication of James Gleick's Chaos (1988) and the computer representations of strange attractors and fractals. Though "chaos" is actually a technical term for "deterministic behaviour which looks random" (MacKay, 1994, p. 74) or "orderly disorder" (Gleick, 1988, p. 15), its evocative associations accompanied by compelling visual rhetoric has firmly planted chaos in the public consciousness as the name of choice for this area. However nonlinear scientists themselves do not tend to use the term except in its technical sense, preferring terminology which grows out of their own particular research agendas.

Katherine Hayles, connecting science and literature, prefers chaos precisely because of its rich evocations. Though recognizing that chaos is not in wide use by nonlinear scientists, Hayles (1990) is interested in what happens “when a word such as 'chaos,' invested with a rich tradition of mythic and literary significance, is appropriated by the sciences and given a more specialized meaning” (p. 8). She notes the term’s “ambiguous meanings” (1991, p. 2), feeling its “scientific denotations as well as historical and mythic interpretations” cause it to serve “as a crossroads, a juncture where various strata and trends within the culture come together.” Her belief is that James Yorke’s historical choice of chaos in 1975 for a scientific article,

> tapped into a network of presuppositions that may soon put the emerging science of chaos on a par with evolution, relativity, and quantum mechanics in its impact on the culture. (p. 4)

Yet the term remains problematic precisely because of its connotations and one finds it being used interchangeably with randomness and disorder, undermining meaningful discussion. James Gleick (1988) falls prey to ignoring his own definition in the following example:

> The simplest systems are now seen to create extraordinarily difficult problems of predictability. Yet order arises spontaneously in those systems - chaos and order together. (pp. 7-8)

Though such a maneuver may be merely confusing, opponents of the usefulness of chaos theory sometimes employ such tactics to discredit a body of work they apparently do not understand. In a chapter entitled “Chaos Versus Order and Our Schools,” Spencer Maxcy (1995) claims that,

> rather than assuming that educational phenomena are structured and rationally determinable . . . chaos thinkers challenge the assumption that order is inherent in school organizations. (p. 34)

He then goes on to state that William Doll's work in curriculum theory seeks to "capitalize" on a move from "order . . . toward disorder and irregularity" (p. 35). However Doll (1993) draws on another area of the nonlinear sciences, self-organization theory, which focuses not on chaotic systems which appear random while revealing an underlying pattern, but on the organization that can emerge in systems far from equilibrium. So Maxcy misrepresents this work, whether intentionally or not. Of course, such confusion can not simply be blamed on the popular use of the term chaos. Misreadings and multiple readings are common phenomenon in human interpretation.

The nonlinear sciences are a new area, though with an ancient heritage. In such scientific endeavors the right to name things is a sign of discovery and is part of building power and a place in history. Furthermore, as Murray Gell-Mann (1994) suggests in quoting a "distinguished professor, . . . 'a scientist would rather use someone else's toothbrush than another scientist's terminology'" (p. 17). And so we have such new and emerging sciences as the "science of surprise" (Casti, 1994), "fuzzy logic" (Kosko, 1993), "complexity" (Waldrop, 1992), "living systems" (Capra, 1996) and other such catchalls and subdisciplines.

My own preferred use of nonlinear science, as well as postpositivist research, comes in part from my academic socialization. However their usefulness as catchall terms to indicate a wide range of related endeavors causes me to continue with their use. Nonlinear science is a convincing term because the various pursuits gathered together tend to share or reveal certain underlying principles which undermine the linear assumptions of classical science.

Of course, "linear" is also a catchall term for both mathematical concepts and larger scientific perspectives. In a strict mathematical sense linear refers "to a system of equations whose variables can be plotted against each other as a straight line" (Beyerchen, 1992, p. 62). Such equations "meet two simple conditions," that of "proportionality" and of "additivity or superposition:"

> Proportionality . . . [indicates] that changes in system output are proportional to changes in system input . . . implying that small causes produce small effects, and that large causes generate large effects. . . Additivity or superposition, underlies the process of analysis. The central concept is that the whole is equal to the sum of its parts. This allows the problem to be broken up into smaller pieces that, once solved, can be added back together to obtain the solution to the original problem. (p. 62)

These notions both rely on and require definitions of such concepts as "input" and "output" as well as ways of working which will result in linear outcomes. Beyond specific technical details, linear has also come to indicate a more total perspective on the scientific enterprise grounded in mathematics.

What we tend to think of as science can be traced back through many prominent figures. In terms of mathematics, we can look to Galileo as an important figure because he "was the first to carry out systematic experiments and use mathematical language to formulate the laws of nature" (Capra, 1996, p. 113). Galileo (in Capra) wrote that,

> philosophy . . . is written in that great book which ever lies before our eyes; but we cannot understand it if we do not first learn the language and characters in which it is written. This language is mathematics, and the characters are triangles, circles, and other geometric figures. (p. 113)

The emergent forms of science that drew on this work began to represent the world mostly through linear mathematical equations.

Such work was part of a scientific enterprise whose worldview "has shaped our modern Western society and has significantly influenced the rest of the world" (p. 6). This worldview includes such prominent features as the "universe as a mechanical system composed of elementary building blocks," the body as machine, "life in society as a competitive struggle for existence, the belief in unlimited material progress" and the subjugation of women as an aspect of the natural order. For the moment, the mathematical aspects of this story are of particular importance.

Linear science became a powerful force in society with linear mathematics at its core. Turning curves into series of straight lines or, at the very least, simpler curves, throwing out data which did not fit and using other such mathematical techniques taught scientists to view the world in particular ways. These perspectives limited what scientists could see:

> A process of self-selection set in, whereby equations that could not be solved were automatically of less interest than those that could. The textbooks from which new generations learned the techniques, of course, contained only the soluble problems. (Stewart, 1989, p. 39)

Ultimately the educational process of scientists taught them that linear equations are the norm and nonlinear equations are the "exceptions when a more honest appraisal would have exhibited them as the rule." The "linear habit" became so taken for granted "that by the 1940s and 1950s many scientists and engineers knew little else" (p. 83).

While such a perspective produced results like huge bridges that usually did not fall down, it also produced a perspective based on limited cases though most of nature is actually nonlinear when represented mathematically. In addition to the scientists' educational process, one of the key reasons nonlinear equations were pushed aside was that they were so difficult to solve. The introduction of computers was one of the major reasons that the nonlinear sciences were able to emerge. Computers allowed for extended iterations of equations and presented them not as lists of numbers but in graphically "exquisite nonlinear representations" (Combs & Winkler, 1995, p. 52). The most well known examples of these representations are the fractals which quickly became media fodder, appearing on magazine covers and available as computer programs where today anyone with a relatively low cost computer can explore the graphic possibilities.

For some, this shift in representation signals a move from quantitative to qualitative study, in the case of fractals and chaos theory showing "trajectories as topological portraits . . . [which] display the overall shapes of highly complex temporal events" (pp. 52-53). This shift is one that "emphasize[s] process rather than structure" (p. 52). Hayles (1990) offers the example of,

> turbulent flow . . . [which] possesses so many coupled degrees of freedom that even the new supercomputers are inadequate to handle the required calculations. Since doing more of the same kind of calculations that one would use for laminar flow does not usually yield a solution, the difference between turbulent and laminar flow amounts to a qualitative distinction, an indication that another kind of approach is needed. (p. 13)

Nonlinear mathematics leads to a shift in perspective from the reductionist, analytical bent of classical science to an emphasis on the relationships of the parts and the whole. Where linear science assumes that the sum of the parts equals the whole, nonlinear assumes that the sum of the parts can be more or less than the whole. Linear determinism emphasizes that A causes B causes C while nonlinear determinism acknowledges that things happen for a reason but the web of events is complex and a single cause can rarely be identified in understanding what occurs in the world around us.

Whereas linear science believes it can predict what will happen next and then control the outcome, nonlinear science tends to give up exact prediction and traditional modes of scientific control of events. These shifts have encouraged some nonlinear scientists to suggest that the field is heading towards a "nondisciplinary, integrated science which actually goes beyond science" (Goodwin, 1994, p. 672). This movement beyond may go not only into the social sciences but also into the arts and require new forms of education for scientists.

Such changes lead writers to talk about paradigm shifts at the level of a shift in world view while others see nonlinear techniques as an opportunity to expand scientific business as usual. Of course, the term paradigm is used in many ways as Thomas Kuhn (1970) himself points out about The Structure of Scientific Revolutions:

> In much of the book the term 'paradigm' is used in two different senses. On the one hand, it stands for the entire constellation of beliefs, values, techniques, and so on shared by the members of a given community. On the other, it denotes one sort of element in that constellation, the concrete puzzle-solutions which, employed as models or examples, can replace explicit rules as a basis for the solution of the remaining puzzles of normal science. (p. 175)

He goes on to admit that Margaret Masterman "prepared a partial analytic index [of the first edition] and concluded that the term is used in at least twenty-two different ways" (p. 181). Donna Haraway (1976) refers to Kuhn's preferred meanings as "communal" and "exemplar" (p. 3). These forms of paradigms are more internal to scientific communities and working groups. A third meaning, that of paradigm as worldview, is in much wider circulation.

For some the paradigm shift from linear to nonlinear is at the level of communal work and exemplary projects, including simply adding new techniques to scientists' arsenals. Hayles (1991) points out that,

> the science of chaos . . . is normal science. Its criteria for evaluating evidence, reproducing results, credentialling investigators, and so on, differs not at all from those of other physical sciences. Thus its insights have evolved within contexts that partially reinscribe the very assumptions these insights draw into question. The result is no simple revolution in which a new view replaces an old. (p. 4)

More extreme examples of business as usual include those who intend to control chaos (e.g. Gilmore, 1993; Glenn, 1996; Ott & Spano, 1995; Yamaguti, 1994). For these researchers, nonlinear science has simply opened up new realms of investigation for those with linear viewpoints. Certainly the growing examples of animal experimentation in the nonlinear sciences present the opportunity for further critiques of business as usual (e.g. Ditto, 1996; Madar, 1988).

In contrast, those who perceive a shift in worldview often seem intent on pushing nonlinear science towards a new understanding not just on a technical level but in terms of how and why science is done and for whom. At a minimum, new limits are placed on science:

> The nonlinear revolution provides concrete reasons why extreme claims of prediction, control, quantification, and reduction are false. Science can still do all of these - to an extent - but there are very strong restrictions on scientific ability to know, control, predict and reduce. (Goerner, 1994, p. 21)

From an even more hopeful standpoint, a holistic, ecological perspective emerges which offers the possibility of nothing less than renewal for the earth and its inhabitants (Capra, 1996). This wide range of possibilities suggests that no particular outcome is inevitable for future development, in keeping with nonlinear science's undermining of prediction. Talk of paradigm shifts and multiple outcomes have even stronger resonances in the world of the postpositivist researcher.

Post Does Not Just Mean After

"Postpositivism" embraces an even more unruly set of pursuits than does nonlinear science, including a variety of perspectives, such as Marxism, feminism, phenomenology, poststructuralism and postmodernism, which often cross and combine disciplines. What these perspectives share is a critique of positivism though some, such as phenomenology, are opposed to positivism. Others, such as Marxism, include many elements which positivism excludes while simultaneously maintaining elements of positivism such as linear notions of progress.

We can also speak of postpositivism as a paradigm much like that of nonlinear science because positivism is generally representative of the attempt to apply the insights and approaches of the physical sciences to human behavior. Yet, while positivism signifies the use of linear perspectives to create human sciences, postpositivism does not therefore indicate the human version of nonlinear science, though it does represent a paradigm shift. In addition to being what comes after or in response to positivism, postpositivism has resulted in a shift from a dominant paradigm to a multiplicity of perspectives, perhaps even a postparadigmatic diaspora. Nonlinear science can be said to be a successor regime to linear science's dominance without negating the gains of linear science. In contrast, postpositivism contains the possibility of a shift away from dominant paradigms and successor regimes which allows positivism to continue while deprivileging its dominant position.

"Positivism" as a catchall refers to the importation of scientific methodology from the natural sciences into the human sciences. August Comte is credited as the originator of this project in the early 1800s, a project which has gone on to take many forms. In its current manifestation, positivism is a paradigm based in linear science at the communal, exemplar and worldview levels. In particular, Newtonian physics is taken as a model in which the researcher is separate from that which is researched, strict objectivity is believed to be maintained, the researcher is simply attempting to discover a real world which exists all around us and prediction and control are paramount. In the human sciences, positivism has allowed for the ascendancy of analytical methods which often draw on statistical approaches to mathematics. Again we see linearization techniques used to draw conclusions from phenomenon, in this case human, which are largely nonlinear.

Many of these values are invoked by the phrase, "the scientific method." The notion of the scientific method has come under a sustained critique which has only built in intensity and sophistication in recent years. This critique has occurred in multiple disciplines and is part of an interest in science as a social or cultural construction. Fieldwork focused on what scientists actually do has revealed "many practices called 'science' by their practitioners . . . [and] many methods called 'scientific methods'" (Traweek, 1996, p. 143). As Traweek points out, "each research subfield has its own distinctive research practices. Hence, the proper terms are plural: sciences and scientific methods."

In addition to differences between disciplinary practices, there are historical differences as well. If, for instance, positivist researchers take the natural sciences as their model, Martyn Hammersley (1991) replies that,

> we must consider which natural science we are taking as the model, and during which period of its development. There are significant differences, for example, between physics and biology; and, indeed within each natural science discipline over time. . . Which interpretation of the methods of natural science is to be adopted? . . . What aspects of natural science method are to be treated as generic? (pp. 167-168)

Such discussions reveal that “textbook versions” of the scientific method which “dominate education” are “storybook image[s]” which “falsify science” (Reason & Rowan, 1981, p. xvi). To continue to hold on to storybook methods is “to signal that one is unfamiliar with the massive body of scholarship that has undermined them” (Traweek, 1996, p. 141).

Criticisms of the scientific method often cluster around the notion of objectivity. The belief that one can be separate from what one researches and that such separation ensures the truth value of the information so revealed is a basic tenet of positivism. This belief has broken down at every level, from how such objectivity is obtained via the scientific method to claims of “social neutrality” (Aronowitz, 1996, p. 207) from a scientific enterprise deeply implicit in warmaking and social control.

Yet such critique does not necessarily imply that postpositivists have rejected concerns with the validation of knowledge claims. One response is the concept of “strong objectivity” (Harding, 1993, p. 19) which would consciously account for rather than seek to eliminate so-called bias and require a systematic examination of “all of the social values shaping a particular research process” (p. 18). This development of new methodologies offers a wide “array of alternative ways of knowing” in which the “focus has shifted from 'are the data biased?' to 'whose interests are served by the bias?'” (Lather, 1991, p. 14).

The debate over objectivity includes feminists within the natural sciences who are raising the issue of how to proceed in such fields as biology and wondering what would happen,

> if scientific objectivity were defined not as an attitude of separation and detachment between scientific actors and the passive objects they manipulate but as a cooperative venture in which scientists and their research subjects are partners. . . What would science look like if it respected the living organisms it studies as individuals with their own histories and integrities? What would it look like if scientists thought of other organisms as rational and capable of intelligent thought? (Birke & Hubbard, 1995, p. ix)

These questions are raised partly in recognition of the "consequences . . . of the pursuit of 'objectivity'" (p. 1) which have "often led to inhumanity, for what is human or humane about an interaction that denies one actor agency while giving power to the other?"

Reevaluating objectivity to include those who are researched is an important aspect of postpositivism more generally. Donna Haraway (1991) calls for a "situated knowledge [which] requires that the object of knowledge be pictured as an actor and agent" because "coming to terms with the agency of the 'objects' studied is the only way to avoid gross error and false knowledge of many kinds" (p. 198). She argues for 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. (pp. 191-192)

For Haraway, one of the "goal[s]" of such practices is "better accounts of the world, that is, 'science'" (p. 196).

With such work in mind, we can speak of the "failure of positivism," if not of funding for positivism, and of "the possibilities offered by a postpositivist era" (Lather, 1991, p. 2). Lather describes postpositivism as "the loss of positivism's theoretic hegemony in the face of the sustained and trenchant criticisms of its basic assumptions" (pp. 6-7). It also involves a "turning away from the enormous pretensions of positivism" and "the development of a human science much more varied and reflexive about its limitations" (1990, p. 315). Such a science "does not propose a unified view . . . [and] holds that we do not have access to indubitable truths" (Polkinghorne, 1983, p. 2). Rather than a "school of thought with an agreed-upon set of propositions . . . [postpositivism] is an attitude about knowledge."

While both Lather and Polkinghorne speak of a new or expanded form of science, it must be recognized that postpositivism includes standpoints which disagree at every level of ontology, epistemology and methodology, some of which reject the notion of science. Laurel Richardson (1997) speaks of claims to science as,

> enact[ing] the hierarchal science/nonscience binary, legitimating their work and institutional practices as valid and true, while devaluing and marginalizing nonscience discursive practices. Scientizing social knowledge is thus inextricably linked to the suppression of other ways of knowing. (p. 208)

If the idea of a postpositivist science, or even sciences, is not common ground for postpositivists, a critical perspective towards traditional approaches to science do connect postpositivists, though the details may differ.

Most postpositivists share an interest in forefronting their beliefs in contrast to linear/positivist attempts to ignore such issues. Furthermore they tend to be exploring the possibilities of an expanded notion of research that would include art and literature, whether or not they consider what they do a science. As one postpositivist educational researcher puts it:

> My conception of research is broad. I will count as research reflective efforts to study the world and to create ways to share what we have learned about it. Research can take the forms that echo the forms of the arts and humanities or those of the natural and social sciences. Its forms of data representation are open to invention. Ultimately its value as research is determined by the judgment of a critical community. (Eisner, 1997, p. 8)

Much of this drive to create different forms of research comes from the realization that positivist research does not do justice to human experience. In some cases this realization is strongly voiced. Reason & Rowan (1981) state that,

> it is obscene to take a young researcher who actually wants to know more about people, and divert them into manipulating 'variables', counting 'behaviours', observing 'responses' and all the rest of the ways in which people are falsified and fragmented. (p. xxiii)

Though desiring to move beyond “naive inquiry” (p. xiii), they feel “an undercurrent of hatred and horror about what traditional research does to those it studies [and to] those who do the research” (p. xii). Reason and Rowan are also disdainful of the “dreadful rubbish that is sometimes put forward as scientific knowledge.” They believe that,

> the whole apparatus of experimental method, quasi-experimental method, statistical significance, dependent and independent variables, and so on . . . kills off everything it comes into contact with, so what we are left with is dead knowledge. (pp. xiii)

Reason & Rowan speak of their attempts to develop alternatives as “New Paradigm Research.” For other postpositivist researchers, the notion of a paradigm shift is inadequate and is giving way to a postparadigmatic diaspora.

Life in the Postparadigmatic Diaspora

The notion of a paradigm shift in the human sciences is one which is applicable at any level, however the sense of a shifting worldview is particularly acute with postpositivist researchers. While some would reject the linear/positivist ways of operating, for the most part one sees an opening up of possibilities and an emergence of multiple forms of research. Rather than a shift from an old way to a new way of doing business, postpositivists are fighting simply to have space in the current setting. For now, positivist research still has institutional priority and postpositivist research gains ground in one area while losing ground in another. Certainly the space won for qualitative research is one example of the battles being fought successfully by postpositivists.

If “the essential quality of a paradigmatic shift is that it presents a discontinuity with the previous world-view and methods” (Reason, 1988, p. 9), then much of what we now see across fields has such a quality. Yet, if we remember that there are many ways of doing science and that each discipline and subdiscipline has taken different approaches to what they do, then we can only speak of a paradigm shift in the broad stroke of catchalls. Increasingly the notion that “something more fundamental than a 'paradigm shift'” (Lather, 1991, p. 107) is occurring is taking hold.

Marcus and Fischer (1986) speak of this time as something beyond simply “the challenge of newer, interpretive programs of research to reigning positivist ones” (p. x). They point out that “to still pose one paradigm against the other is to miss the essential characteristic of the moment as an exhaustion with a paradigmatic style of discourse altogether.” For such researchers “Kuhnian frameworks . . . diminish the play of multiple emergent knowledges vying for legitimacy” (Lather, 1991, p. 107). Rather we are in a,

> period of experimentation . . . characterized by eclecticism, the play of ideas free of authoritative paradigms, critical and reflexive views of subject matter, openness to diverse influences embracing whatever seems to work in practice, and tolerance of uncertainty about a field's direction and of incompleteness in some of its projects. Such periods . . . are by nature relatively ephemeral and transitional between periods of more settled, paradigm-dominated styles of research.
> (Marcus & Fischer, 1986, p. x)

Yet this may not simply be an interim period. Many postpositivist researchers now reject the notion of a search for a common paradigm, recognizing instead a movement across paradigms, the emergence of strange hybrids and the possible collapse of the concept of paradigm itself. From such a standpoint,

> there may not be one future, one 'moment,' but rather many; not one 'voice,' but polyvocality; not one story, but many tales, dramas, pieces of fiction, fables, memories, histories, autobiographies, poems, and other texts. . . We are not marching in a column toward a common future.
> (Lincoln & Denzin, 1994, p. 584)

The movement from warlike battles between paradigms, the escape from the marching column, indicates a shift to a more playful perspective that is nonetheless not frivolous in intent.

Such a perspective demands that we “delimit the power of powerful interests and metaphysical ideologies to dominate the talk and arrest the play” (Caputo, 1987, p. 262). If such a delimitation is possible we will not be “bankrupt in the matter of a paradigmatic exemplar” but rather will have entered the “postparadigmatic diaspora.” In this diaspora the connections between the nonlinear sciences and postpositivist research are many and varied. The use of nonlinear ideas by researchers in other fields offers an opportunity to see these connections.

Ideas in Circulation

For most postpositivist researchers, the principles and concepts which are emerging from nonlinear science are probably of more interest than the actual math. Yet it should always be remembered that these ideas come from mathematical experimentation, computer modeling or investigations of specific natural processes. Thus they tend to evoke possibilities and offer metaphors rather than proof of a general feature of reality. Nonetheless, introductory articles in education, for example, will often explain nonlinear science by introducing a series of principles or concepts which are quickly divorced from their originating context. The current excitement for researchers is that they provide support or, at least, encouragement for postpositivist social theory. However many of the concepts that have received wide circulation, for example the butterfly effect, are often misinterpreted. Some of the metaphorical extensions surrounding the butterfly effect are reminiscent of ongoing claims based on the Heisenberg Uncertainty Principle.

The Heisenberg Uncertainty Principle is in extremely wide circulation among postpositivist researchers as proof that the observer always affects the phenomenon under observation and so absolute objectivity is impossible. Though interpretations of the various experiments associated with the Heisenberg Uncertainty Principle are still in dispute by physicists (Davies & Brown, 1993), nonetheless this work offers proof of uncertainty only at the level of the “microworld of photons, electrons, atoms, and other particles” (p. 6). For instance “the very act of trying to pin down an electron to a specific place introduces an uncontrollable and indeterminate disturbance to its motion, and vice versa.”

As Katherine Hayles (1990) points out, the “implications” of quantum mechanics are “largely irrelevant for macroscopic bodies that remain stationary or move at ordinary speeds” such as “tables and chairs [which] stay neatly in place unless they are moved” (p. 12). However the nonlinear sciences reveal that “even a microscopic fluctuation can send a chaotic system off in a new direction” (pp. 12-13). Furthermore “the role of fluctuations in nonequilibrium systems shows that . . . randomness remains essential on the macroscopic level as well” (Prigogine & Stengers, 1984, 179).

So McKerrow & McKerrow (1991) are correct in critiquing the many truth claims made for the macroscopic or everyday world based on the Uncertainty Principle alone. Yet they fall into the trap of maintaining that there is only one correct reading of this work. While many postpositivists may have misread or overextended claims based on the Heisenberg Uncertainty Principle alone, they can be said to have made an intuitive leap in keeping with their own perceptions of reality. Rather than simply making a lucky guess that was later proven correct by nonlinear science, the issue of intuition is one place where nonlinear science and postpositivist research may find common ground. The origin tales of nonlinear science are full of moments in which discoveries are described as counterintuitive, i.e. counter to the intuition of linear science. For example Casti’s Complexification (1994) is organized around a series of linear intuitions now brought into question and Gleick’s Chaos (1988) regularly refers to intuition. In any case, current reception of the butterfly effect is similar to that of the Heisenberg Uncertainty Principle.

Butterflies Are Indeterminate

Sensitive Dependence on Initial Conditions, more popularly referred to as the “butterfly effect,” is a nonlinear concept or principle developed from Edward Lorenz’s study of weather. Like much of the work termed nonlinear science, Sensitive Dependence emerged from experiments with computer simulations, in this case of weather patterns. Lorenz reran a series of equations with slightly rounded off numbers which resulted in different patterns from the previous runs. This result was unexpected and, for Lorenz, meant that small errors in weather observations would ultimately result in the inability to predict weather conditions for any extended period (Peitgen et al, 1992). What this result also implied was that small differences in the initial conditions of a weather system would result in different developments, a concept popularized by the idea that a butterfly flapping its wings in one location would affect weather far away and so the butterfly effect.

In keeping with linear/positivist traditions of prediction and control, some scientists assumed “that small modifications, well within human capability, could cause desired large-scale changes” (Gleick, 1988, p. 21). Yet Lorenz felt otherwise. Gleick characterizes the situation of attempting weather control as “like giving an extra shuffle to an already well-shuffled pack of cards. You know it will change your luck, but you don't know whether for better or worse.” Other members of the growing chaos control perspective mentioned earlier draw on additional work by Lorenz which found underlying patterns in chaotic systems which are termed strange attractors.

Whether or not chaos control is a feasibility remains to be seen. In any case, the butterfly effect suggests possibilities about natural systems and its proof is of the action of mathematical equations and computer simulations. However popular reception of this theory has taken it to mean that a small cause is somehow amplified to large effect. The situation is much more complicated because there is never simply one butterfly:

> If a weather system has enough energy to produce a hurricane, then the storm's path will be influenced by butterfly aerodynamics across the globe. However, the system does not amplify small fluid dynamics; rather, it amplifies our inability to predict the future of an individual trajectory in phase space. (James, 1996, p. 41)

Furthermore, “because measurement is never exact . . . although patterns of behavior may appear, within those patterns chaotic systems always are irregular and unpredictable” (Masterpasqua & Perna, 1997, p. 307). Such observations undermine the possibility of exact prediction let alone control.

Much of the misreading of Sensitive Dependence in educational research rests on these concepts. Most often it is taken to mean that some small positive action will result in some great positive response. For instance, “since tiny inputs reverberate into big changes, we can work for transformational results by deliberately influencing the right inputs” (Garmston & Wellman, 1995, p. 10). And “the butterfly effect can be very important to our schools. Small changes can have large effects. What may seem trivial or superficial may turn a school around” (Macchia, 1994, p. 214). Other writers, particularly in administration, share these perspectives (e.g. McLinden, 1995; Stander & Vimla, 1994).

These observations are taken in a hopeful light, exemplified by educational administration journals with butterfly graphics on the covers, for example The Executive Educator (“Chaos,” 1994) and Educational Leadership (“Self-renewing,” 1995). Such hopefulness is used to support admirable ideas:

> The success of implementing the ideas implicit in chaos theory depends on respect for the individual at all levels - for the truly innovative leaders, for the really creative teacher who is

> knowledgeable and reflective, and for the student who would thrive in an atmosphere of both increased freedom and demands. School would be again an interesting place to be and learn. (Macchia, 1994, p. 214)

However one must recognize that Sensitive Dependence suggests that we cannot know the outcome of an action. A small positive action may be part of a larger pattern with mostly negative results. This perception is understood by some writers:

> A program may be well done and well received, but unanticipated organization changes may emerge as a result of the program. These changes could be barriers to success, or they could be beneficial - if unanticipated - outcomes. (McLinden, 1995, p. 17)

Sensitive Dependence on Initial Conditions or the butterfly effect cannot be taken as proof for many of its claims, such as those made for a school system based on a computerized weather simulation. Nonetheless intuitive responses to and metaphorical uses of nonlinear concepts, when grounded in the actual science, may bear fruit and are certainly worth exploring.

It must be noted that when researchers take ideas from other fields it is often in support of perceptions they have already achieved in their own work. Turning to the nonlinear sciences for proof of postpositivist concepts seems to be more of a legitimation move, a way of saying, “see, we were right all along!” What may be a more useful way to proceed is to examine the presence of linear and nonlinear principles, e.g. notions of determinism, as they appear in postpositivist discourse. Such examination will reveal that postpositivist research is often held back by linear perceptions while developing sophisticated sociocultural versions of nonlinear principles. This approach would also allow for engagement with nonlinear science without simply reinscribing the pre-eminence of science as research.

Postpositivist Practice

There are alternatives to the importation of ideas from the nonlinear sciences into postpositivist research more in keeping with the concept of the postparadigmatic diaspora. Working within and across both areas will not result in a single approach or paradigmatic exemplar. This is a time when multiple possibilities are emerging in practice as ways of proceeding, as inspirations rather than blueprints. The idea of postparadigmatic exemplars is touched upon by postpositivist researchers.

Lather (1991) points to "practice as a privileged site for working out what it means to do emancipatory work within a post-foundational context" (p. 116). She describes her recent work as "situated in efforts toward generative research methodologies that register a possibility and mark a provisional space in which a different science might take form" (Lather & Smithies, 1997, p. 127). Polkinghorne (1983) maintains "that human science requires a syncretic approach which integrates the results obtained through multischematic and multiparadigmatic systems of inquiry" (p. xi). He also believes that it is imperative "for practitioners to experiment with the new designs and to submit their attempts and results to examination by other participants in the debate."

According to Marcus and Fischer (1986), "the most interesting and provocative theoretical works . . . point to practice . . . to a bottom-up reformulation of classic questions" (p. 166, n. 2). Such a statement could also be used to describe the situation in the nonlinear sciences where provocative theoretical works are reformulating the questions of classical, linear science. Furthermore, just as the postparadigmatic diaspora calls for practice which proceeds without always knowing where things are going, the nonlinear sciences are working themselves out in practice, project by project, not always knowing what the next step will be.

While both nonlinear and postpositivist projects sometimes end up looking like normal science/research, in both areas we see an emergence of art and aesthetics as a valid concern for the researcher. Just as visual representation is forefronted in nonlinear science, alternative forms of data presentation are being explored by postpositivist researchers (e.g. Eisner, 1997). For Alan Beyerchen (1989) "one of the most promising implications of nonlinear science is a narrowing of the gulf that so often separates persons in the arts and humanities from those in the sciences" (p. 45).

Beyerchen points out that "complexity and ambiguity have long been regarded as weaknesses of the humanities" (p. 46). He traces the origins of the "quest for clarity at the cost of context" to the seventeenth century where such thinking emerged as a "defining feature of science," ultimately defining much of Western culture. Beyerchen recognizes that,

> ambiguity has remained a positive abiding concern only in humanistic studies, particularly in the realms of history and literary theory. . . As we expand our pictoriate intuition in response to the aesthetic of complexity emerging from nonlinear science, scientists may join with humanists in recognizing ambiguity not as confusion, but as a legitimate boundary state that offers enhanced possibilities for understanding the contextual dimensions of reality. (pp. 46-47)

However as one looks at the work coming out of the nonlinear sciences, it is hard not to feel that they are taking baby steps in such matters at a time when postpositivist researchers have developed quite sophisticated ways of mixing science and art. Laurel Richardson has been in the front lines of such work with her sociological poetry and dramas. In addition to such projects, Richardson (1997) points more generally to the work of researchers whose "analyses show that literary devices appear in all writing, including scientific writing" (p. 18). Such literary devices "affect how ideas are formed, how field notes are taken, how survey questions are phrased, how the work is written up, and how readers make sense of it." Richardson maintains that "once we fully recognize this . . . we can lay claim to a science that is aesthetic, moral, ethical, moving, rich, and metaphoric as well as avant-garde, transgressing, and multivocal." One example of a science/literature that moves in and across nonlinear, postpositivist territory is the work of Michel Serres.

Michel Serres

Michel Serres is a French historian and philosopher of science whose work “is literature-and-science” (Hayles, 1990, p. 202) and for who “the idea of a workable passage between the exact sciences and the sciences of man is never far from his mind” (Girard, 1989, p. vii). He is a “'voyager' between the arts and the sciences” (Lechte, 1994, p. 82) whose writings trace the passage of the voyager who can not sit still,

> [who] is not an author for those people whose intellectual life consists in 'keeping up with the literature' in one of our constantly shrinking 'fields' and in believing that steady progress is being achieved simply because, as the field gets smaller, the objects left in it look larger. (Girard, 1989, p. viii)

Though Serres's work, except for those explicitly historical works in translation, generally appears to be more literature or philosophy than science, he “firmly believes that the very viability and vitality of science depends on the degree to which it is open to its poetical other” (Lechte, 1994, p. 85). For Serres,

> the poetic impulse is the life-blood of natural science, not its nemesis. Poetry is the way of the voyager open to the unexpected and always prepared to make unexpected links between places and things. (p. 85)

Serres commits what is for many the unpardonable sin of discussing scientists and artists of different times as if they were with us now, working together on related ideas. He argues that,

> in literary works one sometimes finds perfect intuitions of scientific instruments that come later. It sometimes happens that the artist - musician, painter, poet - sees a scientific truth before it is born. (Serres & Latour, 1995, p. 99)

Furthermore, Serres feels “that there is as much reason in the works of Montaigne or Verlaine as there is in physics or biochemistry” (p. 50).

Conversely, he maintains “that often there is as much unreason scattered through the sciences as there is in certain dreams.”

Serres also connects nonlinear science and postpositivist research through the concepts upon which he draws. One example is his notion of time as flowing not “according to a line,”

> but, rather, according to an extraordinarily complex mixture, as though it reflected stopping points, ruptures, deep wells, chimneys of thunderous acceleration, rendings, gaps - all sown at random, at least in a visible disorder. Thus, the development of history truly resembles what chaos theory describes. (p. 57)

Such a notion allows him to relate the work of Lucretius, writing in the 1st century B.C., to the “modern theory of fluids . . . as in the same neighborhood” (p. 57). Not only does he draw on nonlinear concepts but he uses them to inform his own methodology.

Each volume of Serres's work reveals not only constant movement within a project but continual transformation from project to project. His descriptions of Lucretius's work which “launches us into movement” (p. 107) might as well apply to Serres's own. Both of their “vortices . . . bring things together, forming and destroying worlds, bodies, souls, knowledge, etc.” Serres’s description of Lucretius quickly becomes a methodological exhortation to “stand up, run, jump, move, dance! Like the body, the mind needs movement, especially subtle and complex movement.” Yet key concepts Serres developed through Lucretius are eventually left behind, in particular the idea of a science of Venus and Mars.

Serres's “seminal essay” (Hayles, 1991, p. 17) “Lucretius: Science and Religion" is discussed both in N. Kathryn Hayles's edited volume Chaos and Order (1991), which gathers essays working across the divide of science and literature, and in her own extended project Chaos Bound (1990). Hayles, a trained chemist and practicing literary theorist, discusses Serres's conception of “the linearity of Martian order” (1991, p. 18) which “privilege[s] war over love, order over creativity, abstraction over embodiment, aggression over sympathy, death over life.” This order contrasts with the “birth of Venus” which shuns “linear reason and fragmented analysis" taking "as its emblems the vortex, the wave, the cloud, the waterfall." Hayles feels that Serres relates Mars to "values [which] have been predominant in the West through a long, bloody history of war and conflict." In addition, through taking Venus as a nonlinear symbol, she finds that "Prigogine and Stengers . . . endorse and amplify Serres's suggestion that chaos represents not just hitherto unrecognized phenomena but an unjustly neglected set of values."

Serres (1982) speaks of the "nature of Mars" as "one of hard, rigid, and rigorous bodies" while the "physics and nature of Venus are formed in flows" (p. 103). Eric Charles White (1991) discusses this opposition:

> Where Venus proposes a 'science of caresses' valorizing stochastic processes, Mars insists on a 'science of death' according to which reality can be reduced to deterministic trajectories. . . Venus's desire for nonagonistic cooperation in the social realm can never coexist with a martial politics of domination and totalizing control. (p. 266)

Though a satisfying opposition, White goes on to point out that, as Serres's work continues, he "finds himself increasingly unable to maintain a distinction between the respective sciences of Mars and Venus" (p. 274). As order emerges from chaos "there ensues a process of progressive elaboration as the new system strives toward maximum scope and power" (p. 275). Inevitably "emancipatory innovations inaugurate disciplinary norms" and so Venus "becomes her antithesis." White's reading of Serres concludes that the "martial regime of deterministic trajectories can never permanently be overcome by stochastically emergent turbulence."

What does remain is an opposition to war and oppression which is an important aspect of Serres's critique of both science and education. In contrasting Venus and Mars, Serres (1982) claimed that,

> Western science . . . has opted for war and plagues, for brawls, blood, and bodies burnt at the stake. Western science, from Heraclitus to Hiroshima, has only known martial nature. (p. 99)
> . . .It is difficult to think of a rigorous and exact science that might have been conditioned by Venus and not by Mars, for

> peace and not for destruction, by a contract and not by a strategy, by workers and not by generals, since Western science has always followed the weight of power. (p. 106)

Later, after giving up this opposition of Mars and Venus, Serres (1995) remains concerned with war and science stating that,

> the endeavor that was no doubt born in the classical era had to end in the Los Alamos desert, at the place where all the grains of sand look alike, where the work of men still vitrifies them. (p. 73)

Serres makes connections between science, war and violence that intersect with knowledge production and education. His argument brings Eisner's "critical community" (1997, p. 8) into the realm of Michel Foucault's (1979) concern with discipline and surveillance, though he does not reference his former teacher and colleague directly. As Serres (1995) points out,

> the sciences amongst themselves perform a surveillance, a monitoring that is both conceptual and social, and which defines the validity of a learned procedure. Consensus is the ensemble of these monitorings. At a given time, the community knows, as though instinctively, what is admissible. To be learned is to have this knowledge, often without knowing it. (p. 104)

This monitoring "becomes a social constraint on thinking more than an exercise . . . with invention in mind" (p. 105). Serres feels that such surveillance is "happening, right now, throughout the scientific and scholarly institution, everywhere within the university."

Serres (1997) draws from his own life in critiquing educational institutions and comparing them to institutions of war. He declares that "there is no difference between the purely animal or hierarchical customs of the playground, military tactics, and academic conduct" and that "the same terror reigns in the covered playground, in front of torpedo launchers, and on campus" (p. 134). He recounts that, as a "postwar French university philosopher," he "uneasily survived ten diverse terrors maintained by theoreticians who were serfs to political or academic ideologies" (p. 135). Serres characterizes such theoreticians as,

> director-princes of groups controlling beneath their pressure the space of the campus, appointments, and footnotes, forbidding all freedom of thought at all cost. (pp. 135-136)

Such a situation caused him to develop "some rules of ethics" which differ from much academic conduct:

> After attentive examination, adopt no idea that would contain, on the face of it, any trace of vengeance. . . Never throw yourself into a polemic; Always avoid all membership: flee not only all pressure groups but also all defined disciplines of knowledge, whether a local and learned campus in the global and societal battle or a sectorial entrenchment in scientific debate. Neither master, then, nor above all disciple. (p. 136)

Serres does not think of these rules as a method but rather as "an exodus, a capricious and seemingly irregular trek constrained only by the obligation to avoid speculative places held by force, generally watched over by guard dogs" (p. 136).

Yet this exodus has not caused Serres to abandon the notion of education. In fact, his understanding of what education can be is much like his thoughts on writing and research. The translators of The Troubadour of Knowledge (1997), Serres's extended meditation on learning, state that the book's original title, "'Le Tiers-Instruit' - literally, 'the third-instructed (one)' or 'the instructed third'" is a reference to a "third kind of instruction outside the dominant first two: outside scientific and literary education, or the natural and human sciences" (p. ix). Instead they chose the title, The Troubadour of Knowledge,

> to reflect Michel Serres's identification of the third-instructed with the figure of the troubadour, his equation of learning and knowing with finding and inventing. Throughout the text, knowledge, learning, and philosophy are linked to travel, to seeking and encountering, to the intersection of genres and disciplines. (p. ix)

In this work, Serres's metaphor of education is the crossing of a river, when one is in the middle, no longer leaving one shore nor yet approaching the other. His discussion eventually goes beyond even the notion of the third:

> Did you believe it to be triple? You are still mistaken, it is multiple. .   . You were unique and had a point of reference, you will become many, and sometimes incoherent, like the universe, which, it is said, exploded at the beginning in a big bang. . . The voyage of children, that is the naked meaning of the Greek word pedagogy. Learning launches wandering. (pp. 7-8)

To Be Continued

Michel Serres offers us one or, better, multiple examples of not simply connecting the nonlinear sciences and postpositivist research, but of working in a postparadigmatic diaspora in which our voyaging takes us from site to site in widely scattered locales. The traces of our journeys, the writings left behind, become local yet mobile sites of knowledge. As we continue to travel, we discover moments when linear approaches offer useful tools yet nonlinear maps best communicate where we have been, where we find ourselves, where we are going.

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