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Another Approach to Interdisciplinary Studies

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***Abstract*:** Newell's "A Theory of Interdisciplinary Studies" is criticized for its undefined and inadequate borrowing of the term nonlinear from chaos theory and the repeated use of this term as a *deus ex machina* to explain emergent or self-organizing behavior. His theory is unable to model complex behavior or to distinguish, as he wants to do, his definition of complexity from the complexity generated by chaos theory or neo-evolutionary biology. His theory does not clearly distinguish systems and processes that produce phenomena and the system and process that produces knowledge of phenomena. His theory, it is argued, paints an unrealistic picture of what the interdisciplinary scholar does. An approach to interdisciplinarity that contrasts with Newell's is then put forward. The incremental nature of scholarly work combined with the system and process of knowledge production is shown to be analogous to the process of iteration through nonlinear equations of chaos theory and fractal mathematics. Interdisciplinary scholarship is viewed as similar to discipline scholarship, but too often, interdisciplinary scholarship does not become part of an iterative, ongoing system and process.

Introduction

THIS PAPER HAS TWO OBJECTIVES. The first is to provide a response to Bill Newell's "A Theory of Interdisciplinary Studies." I will set out criticisms of Newell's theory that show it to be an inadequate theory for interdisciplinary studies. My second objective is to propose a more adequate approach to a theory for interdisciplinary studies based on chaos theory and fractal geometry.

Response to the Paper "A Theory of Interdisciplinary Studies"

Whose Complex Systems Theory?

I believe that Newell's paper would be more appropriately titled A New Theory of Complex Systems with Application to Interdisciplinary Studies. The paper, as it is currently titled and written, might mislead a reader unfamiliar with the various systems theories. For example, Newell writes, “modern notions of complexity have their roots in theories of chaos, *complex systems*, fractal geometry, nonlinear dynamics, second-order cybernetics, self-organizing criticality, neo-evolutionary biology, and even quantum mechanics” (p. 6, italics added). Reading this, one might assume that complex systems—like the other theories listed—is a well-developed and applied theory with a supporting body of literature, and that Newell is just applying this preexisting theory to interdisciplinary studies. This is not the case. In fact, Newell constructs his own complex systems theory. Perhaps Newell means to warn the reader that complex systems theory is his own creation by the statement: “I believe the approach to complexity most fruitfully applied to interdisciplinary studies comes out of the study of complex systems, *though my thinking is shaped by the entire set of theories”* (p. 7, italics added). Still, I believe room for confusion exists because including complex systems theory in a quote with theories that *do* have a supporting body of literature erroneously implies that complex systems theory does as well. Complex systems theory’s supporting literature is in fact constructed in Newell’s paper, although it does borrow from these other theories.

The Problem of Borrowing

Newell wisely warns that “borrowing from theories of complexity is complicated by their diversity; . . . any generalizations” about notions of complexity “must be made with caution; . . . similar and even identical terms applied to different forms of complexity take on somewhat different meanings because of the difference in theoretical context” (pp. 6-7); and “many scholars draw rather indiscriminately from the various literatures” (p. 7). Unfortunately, Newell did not consider his own warnings as he constructed his complex systems theory.

To illustrate this, I will consider his use of the term *nonlinear*. Nonlinear is a key concept in Newell’s theory of complex systems. The term is used seventeen times in the paper, four times in two paragraphs where he explains how complex behavior is produced in this theory (pp. 6-7). “Nonlinear” functions as a *deus ex machina* in his complex systems theory to account for emergent or self-organized behavior or structure. Newell believes this explains the notion of *integration* which is so important for interdisciplinarity. He writes, “Because the various facets are connected by *nonlinear* relationships, the overall pattern of behavior of the phenomenon (and thus the system) is not only *self-organizing* but also complex” (p. 2, italics added). Yet, this key concept is never defined in “A Theory of Interdisciplinary Studies” (e.v.).[1] Nonlinear equations or nonlinearity in equations is a very specific concept in mathematics (Parker, 1997, p. 167). It implies nothing about self-organization or emergent properties. It is taken over by nonlinear dynamics—or chaos theory—and fractal geometry—in its technical mathematical meaning—and then combined with another technical mathematical procedure, *iteration* (Stewart, 1989, p. 18). Chaos theory and fractal geometry *combine* an iterative procedure of nonlinear equations to produce complex emergent behavior or structure like the Mandelbrot set (Mandelbrot, 1977). In other words, *it is not nonlinearity alone that produces emergent or self-organizing behavior or structure. It is the* combination *of nonlinearity* and *iteration that produces this*. As the song says, love and marriage [like nonlinearity and iteration] “go together like a horse and carriage. *You can't have one without the other”* (italics added). Yet, in the seventeen times the term nonlinear is used in Newell’s paper, it is never combined with iteration. In fact, Newell presents nonlinear and iteration in contrasting terms. “In particular, interdisciplinarians must ask: is complexity located in the structure or behavior of a system; is it generated by iterative solutions of a single equation *or* by nonlinear relationships among a large number of variables” (p. 7, italics added). He goes on to declare, “nonlinear dynamics is grounded in chaos theory and *suffers the same shortcomings* for interdisciplinarians” (p. 12, italics added). In fact, the iteration of nonlinear equations; certain autocatalytic chemical reactions; and iterative, algorithmic procedures from neo-evolutionary biology *provide the key mechanism for modeling complex emergent or self-organizing structures or behavior.* Even Prigogine, the great theorist of self-organizing systems far from equilibrium, falls back on these paradigm models from chaos theory of iteration of a nonlinear equation and the autocatalytic chemical mechanism for emergent or self-organizing behavior (Nicolis and Prigogine, 1987).

Newell grants that chaos theory, “where behavior is generated by the iterative solution of simple unchanging equations,” can generate complex structures like the Mandelbrot set (p. 12), but note the interesting absence of nonlinear equations here; he is consistent in separating nonlinear and iteration. Furthermore, Newell is insistent that chaos theory is not useful for interdisciplinary studies. He therefore attempts to define a different complexity than that produced by chaos theory. He writes, “Specifically, the theory of interdisciplinary studies I am advocating focuses on the form of complexity that is a *feature of the structure* as well as the behavior of a complex system, on complexity generated by *nonlinear* relationships among a large number of elements and relationships of the system on its overall pattern of behavior" (p. 7, italics added). Note that iteration is again missing, so his attempt to discriminate the complexity of "complex systems" from those generated by chaos theory is marred by inaccurate and incomplete borrowing of nonlinear from this theory. Without iteration, nonlinear is a mysterious *deus ex machina*.

How, one might ask, would one be able to determine whether the structure or behavior of a system in the world was the complexity modeled by chaos theory or Newell's complexity? I maintain that the only way to distinguish between these complexities would be to model the behavior using each theory and see which is the most adequate for the phenomena under study. But how can Newell's theory model phenomena with his mysterious nonlinear relationships? Newell's view of complexity, given the inaccurate borrowing of nonlinear, would seem to come down to the view that complexity is the result of complexity of structure. But what is the value of a theory based on the tautology that *complexity is the result of complexity*? Without a mechanism, I do not see the *theory* in Newell's *complex systems theory*. In the latter part of this paper, an approach to a theory of interdisciplinary studies is set out based on chaos theory.

Systems and Processes that *Produce Phenomena* Plus a System and Process that *Produces Knowledge* of Phenomena

Newell asks us to see what acid rain, rapid population growth, and the *Autobiography of Benjamin Franklin* have in common. However, it is also important to see how these examples are different. One of the problems of Newell's theory is that it does not clearly keep in mind the differences between phenomena or behavior like acid rain and human population growth and the collection of papers responding to Franklin's autobiography. Two sets of systems and processes are at work here, and both must be taken into account. The first is the systems and processes that *produce the phenomena* scholars study, and the second is the, I will argue, singular system and process that *produces knowledge* about the phenomena studied. Of course, the two sets are related, but it is important to keep both clearly in mind. Acid rain and rapid population growth are the result of the first kind of systems and processes. The *knowledge* about these is the result of the second system and process which, no matter what the discipline, tends to have an underlying similarity. Thus, human populations are produced by human sexual activity that is embedded in and affected by cultural systems. Our *knowledg*e about human populations is produced by several disciplines, e.g., biologists researching biological reproduction and birth control, sociologists studying how cultural beliefs and values structure and affect sexual activity, economists studying how economic factors affect birth rates, etc. While the current array of knowledge about human population growth may be complex, I believe the underlying process of scholarly knowledge production is similar in the above disciplines, and fairly simple. Newell's example of the legacy of scholarly reaction and interpretation to *The Autobiography of Benjamin Franklin*, unlike acid rain and rapid population growth, is purely the result of *the knowledge system and process*. If one were to collect all the reviews, interpretations of, and reactions to Franklin's autobiography, there would likely be many, and appear complex. Yet, the process that produced this legacy was a simple iterative or repetitive process. A particular scholar reads Franklin's autobiography, reads other essays and interpretations, combines this with personal knowledge and experience, and produces a new contribution. A later scholar repeats the process, includes perhaps the previous interpretation, and the legacy grows incrementally. But this account is too individualistic and only the first set of steps in the larger context of academic knowledge production. The individual scholarly activity takes place within a discipline system and process that includes a disciplinary education and acculturation, disciplinary professional employment, funding or support for scholarly activity, peer review, and journals that publish scholarly work. This same system and process operates across disciplines, and while it is an essential part of academic knowledge production, I would not call it complex. It is highly iterative or repetitive. The same system remains in place, and the process repeats itself over and over through this system.

Newell finds it necessary to import free will into his theory, and he finds chaos theory and neo-evolutionary biology inadequate because they ignore "the feedback loop humans create from the pattern of behavior to the rule or relationship or equation that generates it" (p. 12). While I would not deny that human choice and free will operate in decisions and actions which humans make, I would argue that disciplinary *and* interdisciplinary scholarship are constrained by the scholarly system and process just outlined. Because of this, chaos theory and fractals may well model the structure of knowledge. This is precisely what I will argue in the latter part of this paper.

Newell, himself, I believe, makes the case that the interdisciplinary knowledge process is not that complex. Whether we take Klein's or Newell's version of the interdisciplinary process, each is composed of about a dozen steps, and these steps usually operate in a linear fashion (i.e., first step one, then step two, etc.). I would not call either of these processes complex. But there is an important absence in Newell's paper. Newell's process is individualistic. The paper omits the social system in which any knowledge production is embedded. It is this social system of education, acculturation, learning important paradigms and methodologies of the field, employment, support for research, peer review, and journals to publish scholarship that operates repeatedly or iteratively and constrains the knowledge system and process. It is this that makes it amenable to modeling by chaos theory and fractals.

The Interdisciplinary Scholar as Heroic, Complex-System Modeler

Newell's theory of interdisciplinary studies presents the individual interdisciplinary scholar as a heroic, complex-system modeler. Thus, "the task for the interdisciplinarian is to focus more broadly on the pattern of acid rain modeled by the complex system as a whole, redefining the problem accordingly" (p. 16). This would mean that one must have a grasp of a model of the complex system to begin interdisciplinary scholarship. But where is this to come from? Newell further argues that, "much of the new knowledge required by interdisciplinarians is unlikely to ever be generated by the disciplines" (p. 18). Thus, an interdisciplinary scholar would have to generate knowledge of the complex system himself or herself. The heroic task that Newell requires is clearly set out. "The task of interdisciplinary integration involves two interrelated challenges: recognizing the overall behavior pattern of the phenomenon being studied, and *constructing a complex system whose pattern of behavior is consistent with that of the phenomenon* while it emerges from its constituent components, relationships, and subsystems" (p. 20, italics added). Further, "even more challenging is the overall pattern of behavior for a system that is complex" (p. 20).

Thus, in his view, the heroic interdisciplinary scholar confronting the phenomena of acid rain would be called on to conceptually construct a comprehensive model of the complex system that produces acid rain. I do not believe any empirical study of interdisciplinary knowledge production would show it operates that way. A Newton, Darwin, or Marx appears rarely, and even such a giant's comprehensive modeling of systems emerges within a social knowledge system and process.

Summary

"A Theory of Interdisciplinary Studies" inappropriately borrows the concept nonlinear from chaos theory and fractal geometry, which it then uses as a mysterious *deus ex machina* to explain emergent self-organizing structures or behavior. It is unable to distinguish its complexity from the complexity generated by chaos theory, or neo-evolutionary biology, or to model complex behavior. It does not clearly distinguish systems and processes that *produce phenomena* and the system and process that *produces knowledge* of phenomena. It leaves out the social system and process in which all individual scholarship is embedded. It paints an inflated and unrealistic picture of what the interdisciplinary scholar does. For these reasons I believe the paper fails to provide an adequate theory of interdisciplinary studies. The next section proposes another approach to a theory of interdisciplinary studies that overcomes these problems.

Another Approach

I believe that the systems that most scholars study are complex, but that the particular issues addressed by an individual scholar are fairly simple. Consider, for example, current research on controlling nuclear fusion or finding a cure for cancer or AIDS. These involve systems of considerable complexity, yet the work of particular scholars doing research in these areas addresses rather simple incremental issues or puzzles. Thomas Kuhn calls this scholarly work in science, normal science (1962). In my view, this process of scholarly work extends to the humanities and to interdisciplinary scholarship as well. Most scholarly work in these areas, like science, addresses relatively simple, incremental issues. An example would be the previously described scholarly work in adding to the legacy of scholarship on *The Autobiography of Benjamin Franklin*. Thus, in contrast to Newell's view of the interdisciplinary scholar as a heroic, complex-system modeler, I see interdisciplinary scholarship as much like that of a scholar adding a new interpretation to Franklin's autobiography. Interdisciplinary scholarship does not usually involve the construction of some grand, complex-system model. It is rather an incremental addition and extension of an existing knowledge base. The interdisciplinary scholar may extend his or her knowledge base beyond a single discipline, but that extension is also incremental and only rarely system building. I further give priority to the academic knowledge production system and process of education, professional employment, support for research, peer review, and places of publication.

This scholarly system and process and the incremental nature of individual scholarly work is fairly simple, iterative or repetitive, and nonlinear (addressed below). It is thus modeled well by chaos theory and fractals. I first proposed in a paper presented at the 1993 annual conference of the Association for Integrative Studies at Wayne State University in Detroit, and later published in *Issues in Integrative Studies* (*IIS*) (1993) that interdisciplinarity could be modeled by chaos theory and fractal geometry. Recently, Andrew Abbott (2001) used fractals to explain the patterns of scholarship in disciplines and to comment on interdisciplinarity. Abbott also gives priority to the social system and process that produces knowledge. He shows that knowledge in disciplines has a fractal structure due to "common oppositions that function at any *level* of theoretical or methodological scale. Opposing perspectives of thought and method, then, in fields ranging from history, sociology, and literature...are radically similar; much like fractals, they are each mutual reflections of their own distinctions" (back cover). This is a result, as I have argued above, of the operation of the *knowledge production system* and the incremental nature of individual scholarship, not of the *systems and processes that produce phenomena* as Newell would have it. Abbott supports the view of knowledge production as I have outlined it. "[Elizabeth] Bott was right when she said that what mattered about interdisciplinarity was that interdisciplinary contact modified each researcher individually, *not that it created grand new zones of endeavor*" (p. 230, italics added). Newell's theory requires grand new zones of whole system modeling. In agreement with Bott and Abbott, the approach I am proposing does not. Newell's theory in Kuhnian terms would amount to making each interdisciplinary scholar a revolutionary like a Copernicus, Newton, or Einstein rather than a practitioner of normal research.[2]

Why Interdisciplinary Studies Is Well Modeled by Chaos Theory

I will now show how the system and process of knowledge production is analogous to the iteration of nonlinear equations in chaos theory and fractal geometry. The incremental nature of scholarship as I described for the scholarly legacy of *The Autobiography of Ben Franklin* is, I believe, the pattern for almost all scholarship, even interdisciplinary scholarship. It is analogous to the iterative process of chaos theory. The next scholar to extend this legacy utilizes the previous scholarly work in her area of interest. She will usually begin where the last scholarly publication in her area of interest has left off and proceed through the scholarly process and system. The process could be, for example, the process described by Newell plus the system of peer review and publication. The process and system are an algorithm of steps and interactions analogous to a mathematical equation or sets of equations in chaos theory.

Nonlinearity is a crucial term for Newell and for me. The only way I know to explicate its meaning and how it functions along with iteration to produce emergent behavior is through an actual example. To see how nonlinear interaction operates in chaos theory, consider the simple nonlinear Verhulst equation subject to iteration (Peitgen, Jurgens, and Saupe, 1992, p. 42):

$$y = kx(1\text{-}x), \text{ where } 0 \geq x \leq 1.$$

Consider two parts of the equation, x and (1 - x). These are competing factors in the equation pulling the dependent function, y, in different directions. The x term pulls the resultant value of y toward 1, while the (1 -x) term pulls the resultant value of y toward zero. The k can be considered an amplifying constant in the tug-of-war between the opposing terms. As the amplifying constant is increased, iteration of the Verhulst equation through the competing terms x and (1 - x) that make the equation nonlinear, produces bifurcation, complex patterns, and fractal self-similarity in the outcome of the equation (Mackey, 1995, pp. 109-111). Nonlinear behavior can be viewed as this amplified tension of terms pulling in different directions.

I will try to convey to the non-mathematically inclined reader some sense of what is happening with an analogy. Imagine a tug-of-war between two teams. One team we call the (1 - x) team (This is just a label. We might also call the team the red team or the green team.). The other team we call the x team. The (1 - x) team pulls toward the left, which we call the zero direction, and the x team pulls toward the right, which we call the one (1) direction. A line is drawn on the ground and a red bow is tied to the rope above the line. When a referee blows a whistle, each team tries to pull the other team across the centerline. Let k represent the number of people on each team. We might start the contest with five people on each team. After a while, five more people are added to each team for a total of ten on each side, and the contest continues. Then we could add five more to each side and so on. Consider what happens to the red bow in the middle of the line. It will move around on both sides of the centerline as first one team pulls harder, then tires, and the other team gains. When one team pulls the other team across the centerline the contest stops and the red bow becomes stationary. We can imagine a situation where k, the number of people added to both sides, increases to the point that the tension on the rope causes it to snap in two. This would be emergent behavior. Imagine further, that the rules specify that when that happens the two pieces of rope are both used, and members of the (1-x) and x teams are divided between the two pieces of rope. New lines are drawn and bows are attached in the middle of both pieces of rope. The match is restarted, now with two tugs-of-war taking place. This creation of two games from the original one would be analogous to the emergent behavior of *bifurcation* that happens with the Verhulst equation as k is increased. We could imagine increasing k or members to both sides of both ropes again. At some addition of members, the tension would snap both ropes. The rules call for dividing the teams so that now we would have four tugs-of-war going on or another bifurcation. This process could continue until there were eight tugs-of-war, then sixteen, etc. This is analogous to what happens when iterating the nonlinear Verhulst equation.[3]

Abbott has demonstrated that opposing tendencies operate in scholarship in ways that are analogous to the above nonlinear, iterative behavior and that these tendencies result in scholarly production showing fractal self-similarity. It should be mentioned that more than two opposing factors or tensions also lead to self-similar fractal structures. Abbott uses an example to illustrate the results of opposing tendencies that lead to a self-similar fractal outcome. "If we take any group of sociologists and lock them in a room, they will argue [amplify the tension] and at once differentiate themselves into positivists and interpretivists. But if we separate those two groups and lock *them* in separate rooms, *those* two groups will each in turn divide over exactly the same issue" (2001, p. xvi). Abbott's book is filled with examples of how this iteration through amplified opposing tendencies creates the fractal structure of knowledge in many areas. The opposing tendencies could be opposing perspectives or paradigms from different disciplines. A scholar bringing together the tension of two or more disciplinary paradigms could produce an interdisciplinary outcome (Mackey, 1995, p. 111).

I have shown that the view of scholarship and interdisciplinarity advocated by my approach is analogous to the iteration of nonlinear equations in chaos theory. It has been substantiated by Abbott's work (2001). This approach has a model and mechanism for generating the complex structure of knowledge, whereas Newell's theory lacks such a mechanism, depending only on the *deus ex mechina* of inaccurately borrowed *nonlinearity*.

Consequences

There are consequences to a chaos-based approach to a theory of interdisciplinary studies that gives priority to the knowledge production system and process; the incremental nature of scholarly work; and an iterative, nonlinear mechanism to produce the complex fractal structure of knowledge. One of these suggested by Abbott is that no abrupt demarcation exists between disciplinary and interdisciplinary scholarship (2001, p. 230). Both involve the scholar addressing incremental issues. If the prior knowledge draws completely from within a discipline, we call it disciplinary knowledge. To the extent that the prior knowledge, procedures, paradigms, and methodologies reach beyond one discipline to others, the knowledge can be said to be interdisciplinary. But both the incremental nature of individual scholarship and the knowledge system and process act to prevent the possibility of Newell's interdisciplinary scholar as heroic, complex-system modeler.

The knowledge system and process is primarily discipline based (Abbott, 2001, chap. 5). Knowledge produced by a scholar can draw on other disciplines but only to the extent that it will be accepted and published within the disciplinary system. The scholarship is then incorporated within the discipline's iterative process of knowledge production. But what happens if a scholarly piece of work is seen as too far outside the discipline system to be published in discipline journals? Several possibilities exist. A group of scholars with similar orientations can establish a new interdisciplinary field with its own journals, as women's studies has done. Another possibility is for such work to be published in the few journals that deliberately publish interdisciplinary scholarship, like *IIS.* However, Abbott cautions, and I agree, that this may have very limited consequences (2001, pp. 130-136). The primary problem is that such interdisciplinary scholarship is often not iterative. That knowledge, too often, does not become a part of an ongoing system and process. This suggests that those of us in interdisciplinary studies need to creatively envision ways to make our scholarly work more iterative, that is, focused on previous interdisciplinary work and build on that work.

Biographical note: J. Linn Mackey is Professor of Interdisciplinary Studies at Appalachian State University. He has a Ph.D. in Physical Chemistry and a Master's Degree in Social Ecology. Dr. Mackey is currently interested in science studies and in the interdisciplinary implications of dynamical systems theory and fractals.

Notes

1. In the draft of Newell's paper of 6/11/01, which was the basis of my response, no definition of nonlinear appeared. In the current draft he has added a definition of sorts in a parenthesis "(i.e., with squared terms or even higher powers)" (p. 3). This is an improvement over no definition at all, but it should be pointed out that this is not an adequate definition because it does not include cross terms like xy or zx which are important in many nonlinear equations.
2. I thank Jay Wentworth for reminding me of this.

3. This is an imperfect analogy. For one thing, it would require the multiple ropes to separate at the same instant. Another limitation of this tug-of-war analogy is its inability to model behavior of the iterated Verhulst equation akin to having the multiple tugs-of-war, say sixteen, suddenly recombine to just three teams for some value of k.

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