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A Theory of Interdisciplinary Studies

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Abstract: Interdisciplinarity is necessitated by complexity, specifically by the structure and behavior of complex systems. The nature of complex systems provides a rationale for interdisciplinary study. An examination of complex systems yields new insights into the practice of interdisciplinary study and confirms widely accepted principles for the conduct of interdisciplinary inquiry. Complex systems also unify the apparently divergent approaches to the interdisciplinary study of the humanities and sciences. Most importantly, the distinguishing but elusive characteristic of interdisciplinary studies—synthesis or integration—is at last explained in terms of the unique self-organizing pattern of a complex system.

Introduction

WHAT DO ACID RAIN, rapid population growth, and the legacy of *The Autobiography of Benjamin Franklin* have in common? Though drawn respectively from the purviews of the natural sciences, social sciences, and humanities, they can be fruitfully understood as behaviors of complex systems, and they all require interdisciplinary study. Thinking of each of them as behavior of a particular complex system can help interdisciplinarians better understand such phenomena; collectively, they help us better understand the nature and conduct of interdisciplinarity.

The frequent pairing of complexity and interdisciplinarity is no coincidence. It is the contention of this paper that complex systems and phenomena are a necessary condition for interdisciplinary studies. An interdisciplinary approach is justified only by a complex system. So if a behavior is not produced by a system or the system is not complex, interdisciplinary study is not required.

A convincing case for this sweeping generalization clearly requires in-depth exploration of the concepts of interdisciplinarity and complexity. First, though, a common sense rationale would be nice.

The phenomena modeled by most complex systems are multi-faceted. Seen from one angle, they appear different than they do from another angle, because the viewers see facets (represented as sub-systems) where different components and relationships dominate. Like the phenomena modeled (i.e., represented typically as a set of equations or a diagram) by all systems, their overall pattern of behavior is self-organizing, thus different from the sum of its parts and not fully predictable from them. 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. As such, the pattern is only quasi-stable, partly predictable, and dynamic. An effective method for modeling such a phenomenon must offer insight into its separate facets as well as into the self-organizing, complex pattern produced by their overall interaction. Since the various disciplines have been developed precisely to study the individual facets or sub-systems, interdisciplinary study is a logical candidate for developing specific, whole, complex systems to study such phenomena. By definition, interdisciplinary study draws insights from relevant disciplines and integrates those insights into a more comprehensive understanding.

In order to justify the interdisciplinary approach, its object of study must be multifaceted, yet its facets must cohere. If it is not multi-faceted, then a single-discipline approach will do (since it can be studied adequately from one reductionist perspective). If it is multi-faceted but not coherent, then a multi-disciplinary approach will do (since there is no need for integration). To justify both elements of interdisciplinary study—namely that it draws insights from disciplines and that it integrates their insights—its object of study must then be represented by a system. Because the connections among the facets will be predominantly nonlinear, the system must be complex.

The thesis of this article is that the appropriate focus of interdisciplinary study is on specific complex systems and their behavior. The ultimate objective of an interdisciplinary inquiry is to understand the portion of the world modeled by that particular complex system. In the natural and social sciences, it is widely accepted that each discipline focuses on a set of interrelated variables observable from its perspective. Those variables can easily be seen as components of a system. If there is any coherence to each discipline (i.e., if "discipline" has any meaning), then the variables on which it focuses ought to be more closely and linearly related to each other than to the variables studied by other disciplines. If, as most authors agree, interdisciplinary study draws on more than one discipline's perspective to synthesize a more comprehensive understanding, it must then of necessity encompass more nonlinear relationships (i.e., with squared terms or even higher powers) among the larger set of variables linked together. Seen as a whole, that larger set of variables and relationships can be fruitfully thought of as a complex system. My contention is that we interdisciplinarians can better understand and carry out our craft if we keep in mind that we are developing specific complex systems and studying their behavior. In particular, we can better understand and carry out interdisciplinary integration if we recognize we are attempting to identify and make sense out of the self-organizing pattern of a phenomenon modeled by a particular complex system.

Anticipated Objections Addressed

Fear of Exclusion

My contention that interdisciplinarity is justified only for the study of the behavior of complex systems seems likely to provoke opposition from some interdisciplinarians because the theory appears to limit the legitimate scope of interdisciplinary study. You may ask yourself, “If my pet project turns out not to be the study of a complex system (which I suspect it is not) and this theory becomes accepted, will I be drummed out of the interdisciplinary studies profession?” You may also ask, “Will I now have to justify myself every time I adopt an interdisciplinary approach to study a new problem?” I submit that the answers to those questions are, respectively, “It’s highly unlikely” and “Yes.”

It is highly unlikely that members of the Association for Integrative Studies (AIS) are using an interdisciplinary approach to study an issue, problem, or question that will turn out, upon examination, not to be behavior usefully represented by a complex system. The theory’s differentiation of interdisciplinary study from disciplinary and multidisciplinary study is consistent with current understanding; in fact, it provides a rationale for that understanding. Of course, the theory should not limit the scope of interdisciplinary activity so much as validate the gut sense of interdisciplinarians about when and where an interdisciplinary approach is needed. And yes, interdisciplinarians need to be able to justify their method and determine its range of application, for themselves as well as for their critics. This theory makes that possible by providing a long overdue theoretical rationale for interdisciplinary study.

Humanities Exceptionalism

While the notion that interdisciplinarians study complex systems tends to resonate well with natural and social scientists, it tends to sound strange (even alien) to humanists, not to mention those in the fine and performing arts for whom anything systematic is anathema. The names of the curricular areas in my own interdisciplinary program are revealing of these differences in perspective: we identify the social and natural sciences as Social Systems and Natural Systems but refer to the arts and humanities as Creativity and Culture. After all, scientists tend to feel more comfortable with systems thinking. The humanities and arts are more concerned with behavior that is idiosyncratic, unique, and personal—not regular, predictable, and lawful. If the natural and social sciences focus on the rules that govern behavior, the arts and humanities focus on the exceptions to those rules. Systems thinking seems more relevant to the practical, real-world problem solving of the sciences than to the probing and expression of meaning by humanists. Yet, it is common practice in the humanities and arts to place a text, or author, or work of art into context, to understand it in part through an examination of its historical, geographical, intellectual, or artistic location. While I grant there are meaningful distinctions among the humanities, social sciences, and natural sciences—and that those distinctions affect how interdisciplinarity is practiced in each area—I contend that all interdisciplinarity is, at root, concerned with the behavior of complex systems. The widespread practice of contextualization could be better understood and carried out if scholars and artists were to visualize themselves as looking for the distinctive features of a particular location within a complex system. In general, I believe recognition by humanists of how their work is connected to complex systems will improve interdisciplinary work in the humanities and improve their ability to work with social and natural scientists.

Let's return to my opening example from interdisciplinary humanities, the cultural legacy of *The Autobiography of Benjamin Franklin*. Its legacy is bound up in American literature, history, and culture—fields of study that have distinctive features at the same time that they are interconnected. Even though literary, historical, and cultural perspectives on that legacy will clash to some extent (or the study would be pretty boring), the claim that the book *has* a cultural legacy is a claim that the insights from those diverse perspectives must somehow cohere. They must contribute to the understanding of some larger whole. Yet the connections among literature, history, and culture are better expressed by "influence and response" than by "cause and effect"; they are anything but linear. By even a fairly literal interpretation, then, the cultural legacy can be fruitfully seen as behavior of a complex system. When interdisciplinary humanists search for a theme that captures the cultural legacy, they seek an interpretation that reflects the overall pattern of the complex system.

A study of the book itself, or even of Franklin, may be interdisciplinary or it may not. It depends on whether book or person is seen as embedded in complex forces or one-dimensionally, say as a work of literature (á la New Criticism) or as a historic political figure (á la traditional military and diplomatic history). The beauty of grounding interdisciplinary humanities in complex systems theory is that it provides a hitherto missing rationale for their penchant for understanding texts and individuals as contextualized but unique. Because of the focus of the humanities on free will as well as determinism, that contextualization can refer not only to influences on the text or individual, but also to the ways the book or person gives unique expression to those influences and creates meaning out of them. This rationale is developed further in the section on complex systems theory.

Diverse Motivations

The claim that interdisciplinarity must be concerned with understanding the behavior of complex systems may at first blush seem at odds with the claim Klein and I make in our 1997 survey of contemporary interdisciplinary studies for the *Handbook of the Undergraduate Curriculum*, namely that there are diverse motivations for interdisciplinary study. We list seven:

- general and liberal education
- professional training
- social, economic, and technological problem solving
- social, political, and epistemological critique
- faculty development
- financial exigency (downsizing)
- production of new knowledge (p. 394)

While motives for interdisciplinarity vary, they reflect different consequences of studying complex systems, not different kinds of interdisciplinarity. For example, interdisciplinary courses on phenomena modeled by complex systems promote desirable liberal education outcomes for students, and faculty development for their teachers. Interdisciplinary study prepares future professionals to confront the complex behaviors they will face on the job. It produces new knowledge by synthesizing insights from old knowledge about specific complex systems and by freeing scholars to ask new questions about them. It facilitates fundamental critique by viewing society or politics or knowledge as the dynamic product of a complex of interacting systemic forces. And by partially reorganizing the structure of the university around different categories of complex systems, it reduces the pressure for complete "coverage" of each discipline, thus eliminating an obstacle to downsizing. All seven motivations are consistent with the conception of interdisciplinarity presented in this paper.

One Size Fits All

More problematic are periodic contentions by interdisciplinarians that the very nature of interdisciplinarity varies from use to use. In my 1998 review of professional literature on interdisciplinarity, "Professionalizing Interdisciplinarity," I asked scholars to consider if the nature of interdisciplinarity depends on whether the context is teaching or research, problem solving or radical critique (p. 537). For example, in "Mapping Interdisciplinary Studies," Julie Klein (1999) differentiates between critical and instrumental forms of interdisciplinarity, and distinguishes them from attempts to cultivate integrative capacity through general education (p. 1). These epistemological issues have led to vigorous debates within AIS itself. There has always been a vocal faction of members who caution against definitional closure for interdisciplinarity on the grounds that settling on any definition excludes as well as includes; they prefer to let a thousand flowers bloom. Arrayed on the other side of the debate have been members seeking credibility for interdisciplinary study through conceptual clarity and, ultimately, through standards for judging its quality.

The notion of interdisciplinarity advocated in this paper offers conceptual clarity while embracing a wide diversity of approaches and, for the first time, it sets forth a comprehensive and long overdue rationale. It does exclude as well as include, but the exclusions correspond to widely accepted distinctions between interdisciplinarity and disciplinarity or multi-disciplinarity. More to the point, those distinctions now emerge naturally from the epistemology of interdisciplinarity.

Complex Systems Theory

Which Form of Complexity?

Complexity is not a simple concept. Indeed, borrowing from theories of complexity is complicated by their diversity. 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.[1] Since the details of theories of complexity vary regarding the location, generation, form, and properties of complexity, any generalizations must be made with caution. In particular, interdisciplinarians must ask: is complexity located in the structure or the behavior of a system[2]; is it generated by iterative solutions of a single equation or by nonlinear relationships among a large number of variables; do the components of a complex system produce an overall pattern of behavior or does that pattern, in turn, shape the components; and is the pattern merely self-organizing or is it also self-perpetuating? Worse, similar and even identical terms applied to different forms of complexity take on somewhat different meanings because of the difference in theoretical context. For example, is the emergent behavior of complex systems the same as the self-organizing behavior of chaotic systems? Still, many scholars draw rather indiscriminately from the various literatures. Indeed, these theories are increasingly regarded as forming a new paradigm-in-the-making. Ian King (2001) refers to them as "holistic-relational sciences" and Göktug Morçöl (2000a) calls them the "new sciences."

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. 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 components, and on the influence of the components and relationships of the system on its overall pattern of behavior. The distinctions and commonalities between complex systems theory and chaos theory or nonlinear dynamics are discussed in more detail at the end of this section.

Systems in General

All systems (complex or otherwise) are made up of components that interact, either directly through mutual causation or indirectly through feedback loops, causing an overall pattern of behavior. Those feedback loops can be positive (enhancing the behavior) or negative (dampening or reducing the behavior). Because of those interaction effects, the system as a whole is more than the sum of its parts; indeed, it is different from the sum of its parts. In particular, the organization of components and their interaction produces a distinctive self-organizing, overall pattern or set of patterns of behavior that gives the system its identity. Each sub-system and, as Flood and Carson (1993, pp. 17-19) point out, even each plane of a multi-dimensional system can have its own emergent properties as well.

Kinds of Systems

Let's distinguish three kinds of systems: simple, complicated, and complex (Newell and Meek, 2000).

A simple system may have multiple levels of components and connections arranged in a hierarchy, but the relationships among those components are predominantly linear. Visualize, for example, a state road map. The cities are the components of the system and the highways are the connectors between those components. Larger cities are labeled in larger letters and indicated by larger areas typically colored in yellow. Thicker or more colorful lines similarly indicate larger highways. And larger cities tend to be connected by larger highways. In short, the connections among the components of the system can be expressed as linear relationships, and thus are well behaved.

A complicated system loosely links together simple systems using linear relationships. (Think of a road atlas that links together state maps into a national system.)

A complex system links together combinations of components, simple systems, and even complicated systems using predominantly nonlinear connections. The more components and sub-systems, and the more nonlinear their interconnections, the more complex the system (Cilliers, 1998, pp. 3-5; Flood and Carson, 1993, p. 25; Çambel, 1993, pp. 3-4; Bossomaier and Green, 1998, pp. 7-9). Think of a GIS (Geographic Information Systems) overlay of maps for the same urban area, including not only one of streets and neighborhoods taken from the road atlas, but also maps of water and sewer districts, fire districts, school districts, police precincts, rapid transit, regional planning administration, political wards, ethnic enclaves, the county, watersheds, soil profiles, water quality indicators, and many others. The typical large American city has several hundred administrative units, each charged with the responsibility for one of those maps. Each map represents a sub-system, which can be usefully studied in its own terms from a single perspective. But those sub-systems are connected by an intricate series of often-overlooked relationships that can be subtle, intermittent in their operation, and occasionally produce responses that are disproportionately large or small—in short, by a network of nonlinear relationships. The decisions of the school board about the location of a new school can have unanticipated effects on the ethnic distribution of neighborhoods and thus on voting patterns of wards or traffic patterns, which in turn affect highway maintenance; the resulting political shifts and changing decisions about new highway construction can have unanticipated consequences for watersheds and water quality; and so on. Taken together, the subsystems and their nonlinear connections form a complex system.

Complex Systems

A complex system is composed of components actively connected through predominantly nonlinear relationships. The components can be molecules, cells, organs, phenotypes, species, individual human beings, institutions, groups, nations, artistic movements, cultures—in short, the stuff of the system. The relationships are active in that something flows through the system (Holland, 1995, pp. 23-27), vitalizing it—energy, air, water, information, money, values, signs and symbols—meaning, in general, whatever drives the behavior of the system. Because the relationships are typically nonlinear as well as of varying strength, the flow is not only more rapid in some parts of the system than in others, it accelerates at some points and decelerates at others. Overall, the flow through the nonlinear relationships among the components produces a pattern of behavior.

The pattern is not fully stable and deterministic, as it might be if the relationships were linear, but neither is it ephemeral and random. Rather, the pattern of behavior of a complex system is quasi stable. That is, the pattern is identifiable but evolving, intelligible but not strictly predictable. The key feature of a complex system (indeed, of any system) for our purposes is that its pattern of behavior is self-organizing. As interdisciplinarians would say, it is self-integrating or self-synthesizing.

As a complex system changes size, either growing or shrinking, the nonlinearity of its relationships can produce a nonlinear pattern of transformation over time of the entire system. Thus, the system can suddenly change shape as it evolves, producing a new pattern of behavior (Mainzer, 1994, pp. 237-288). This much is generally understood about complex systems (though flow is often assumed or ignored).

What is typically overlooked in a complex system is that the quasi order of its overall pattern of behavior is accompanied by unique behaviors at each location within the system. An ecosystem as a whole, for example, may be in a stage of succession dominated by certain species of trees, wildflowers, birds, insects, beetles, etc. Yet upon close inspection, it turns out that tiny differences in microclimate give special and unexpected characteristics to each different location within that ecosystem: the dominant species are not uniformly distributed; indeed, every location within it is unique. To take another example from a complex human system, twins sharing the same genetic material and raised in the same household can still develop distinct personalities while exhibiting many common behavioral patterns, in part because they come to occupy unique locations within their social environment. This is not to say that individual variation within a complex system is completely determined by location, so there is no room for free will, genetic variability, or chance; but it does suggest that idiosyncratic behavior is responsive to the specific features of its location within a complex system. In short, place matters. And if one is trying to understand the behavior of a specific place within a complex system, local knowledge matters.

Types of Complex Systems

Not all complex systems are created equal. Biologists know that living complex systems behave differently from non-living ones. Social scientists can appreciate that complex systems whose components are conscious and self-aware behave differently from living systems whose components' behavior is genetically hard-wired. And humanists are alert to the special behaviors of components that can manipulate symbols, imagine, and anticipate the future. As Capra (1996) puts it, "Because of the 'inner world' of concepts, ideas, and symbols that arises with human thought, consciousness, and language, human social systems exist not only in the physical domain but also in a symbolic social domain" (p. 211). Unfortunately, the pioneering work in complex systems theory focused on the natural sciences and mathematics, and too many attempts to extend it have uncritically transferred the theory without adapting it to the new contexts. The further we stray off into the domain of the social sciences and humanities, the more the theory must be modified.

Capra makes a compelling case that living systems are complex systems whose interactive sub-systems contribute to each other's production, maintenance, and development as well as adapting to their environment. Thus, living complex systems are self-organizing, self-correcting, and self-replicating. For example, a cell is a complex, living system in which components such as organelles help produce and transform one another. Non-living complex systems can merely inter-link their sub-systems, while the sub-systems of living complex systems are fundamentally interdependent.

Complex systems whose components are human beings and their institutions diverge even further from non-living systems because humans are capable of exercising free will. There is a gap between stimulus and response in which they make choices. True, those choices can lead to behavior much like that of other living systems if they "follow the path of least resistance" or "go with the flow" and use their mental capacity to rationalize rather than exert rational control over their own behavior. But humans are also capable of exhibiting behaviors that reflect a deliberate balance of morals and values with various forms of self-interest (i.e., wealth, power, or prestige). They can imagine alternative worlds and select behaviors to promote the world they choose. And, after observing the behavior of systems in which they participate, they can learn to anticipate formerly unappreciated large-scale consequences of their actions, and change their behavior to alter a systemic pattern. In the language of complex systems, human components create further indeterminacy in a complex system by turning causal links into mere influences, creating new feedback loops, and even changing relationships that shape the overall behavior of the system.

Applications to Interdisciplinary Humanities

The uniqueness of behavior at each location, and hence the value of local knowledge, has important implications for the application of complex systems to interdisciplinary humanities. Authors, painters, and performers make sense of their unique location within a complex system by expressing its meaning to them in their work. Scholars attempting to interpret or critique their work identify the influences to which it responds. The significance of such influences has long been recognized in the traditional (disciplinary) humanities and fine and performing arts. What complex systems theory contributes to our interdisciplinary understanding of these influences is that they form an overall pattern that promotes unique behaviors at each location within the system. Thus, an interdisciplinary interpretation of a text must reach beyond separate influences to an appreciation of the overall behavioral pattern of the system. And it must recognize the systemic as well as the individualistic sources of uniqueness in author and text.

Other Forms of Complexity

The decision to direct interdisciplinarians toward complex systems theory reflects judgments not only about its utility for interdisciplinarians but also about the pitfalls of drawing from other theories involving complexity. While other forms of complexity may be useful in varying degrees to interdisciplinarians, none seem appropriate as a theoretical base for interdisciplinarity as a whole.

Autopoiesis focuses on a form of complexity where the overall pattern of behavior of a complex system is not only self-organizing, but self-generating and self-perpetuating as well (Capra, 1996, pp. 95-99). Cell biologists deal with such behavior all the time in living organisms, and so do sociologists with society, anthropologists with culture, and political scientists with government. In short, most mezzo- and macro-level behavior studied in the social and biological sciences is probably autopoietic. Indeed, some micro-level behavior may even involve this form of complexity as well—think of the self-perpetuating systems of individual identity produced by individuals—but the humanities may not be well served by a focus on autopoietic complexity. Since every interdisciplinarian deals with behavior that can be fruitfully modeled using complex systems, its more general form of complexity seems best suited to a theory of interdisciplinary studies. Still, interdisciplinarians should be aware of autopoietic complexity and utilize its insight where relevant.

Chaos theory is potentially useful in contexts where behavior governed by a few, simple relationships is endlessly cycled through those invariant relationships; more quantitatively, chaos theory is useful where behavior is generated by the iterative solution of simple unchanging equations. The best-known example of the complexity that results is the elaborate paisley patterns of the Mandelbrot Set. Such behavioral patterns are found, perhaps frequently, in the natural world, and may even be found in the world of humans where habit, routine, or lack of self-reflectiveness dominates behavior; ignorance persists in masking the consequences of behavior; or the behavior is on such a large scale that parochialism obscures the pattern altogether. But most interdisciplinary studies involving the social sciences and certainly the humanities is concerned with behavior of humans who at least learn from the consequences of their behavior, if they don't use their abilities to symbolize and imagine in order to anticipate those consequences and keep them from happening. In other words, the equations do not remain unchanged: however slowly and clumsily, humans modify the rules (equations) that govern their behavior in light of its consequences. Thus, a chaotic form of complexity may not get to completely develop; certainly it will not persist. Nonlinear dynamics is grounded in chaos theory and suffers the same shortcomings for interdisciplinarians.

Neo-evolutionary biology shares with chaos theory the strategy of generating a form of complex behavior through computer models driven by a few simple but invariant rules iteratively applied an extremely large number of times. Thus it appears to have the same limited range of applicability for the same reasons. It ignores the feedback loop humans create from the pattern of behavior to the rule or relationship or equation that generates it.

It may seem strange that quantum mechanics, developed in the first half of the twentieth century entirely within the discipline of physics, is included within the "new sciences." Yet it shares key characteristics—rejection of standard dualisms such as observer and observed, focus on relationships over things, insistence that properties or attributes come out of relationships and are not inherent in things, and the view of properties or attributes as probabilistic and dynamic—with the other theories. In recent decades, a variety of scholars (mostly outside the discipline of physics) have attempted to apply quantum mechanics to much larger scales, even to the world directly experienced by humans. The seldom-stated assumption seems to be that if quantum mechanics operates at extremely small scales, it must somehow operate at larger scales as well, or at least have implications for larger-scale behavior. Once stated, that oddly-reductionist presumption seems out of place among the other theories. Certainly it is a shaky foundation on which to build a theory of interdisciplinary studies.

Connection to Interdisciplinarity

The idea that complexity and interdisciplinarity are somehow interrelated is not without precedent. In "Advancing Interdisciplinary Studies," Julie Klein and I (1997) defined interdisciplinary study as "a process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline or profession . . . IDS draws on disciplinary perspectives and integrates their insights through construction of a more comprehensive perspective"(pp. 393-394). In "Interdisciplinary Thought," Ursula Hübenthal (1994) asserts that interdisciplinary collaboration is required because "[t]hese problems are much too complex to be judged appropriately, much less solved, merely with the subject-knowledge of a single discipline" (p. 727). Marilyn Stember claims in "Advancing the Social Sciences Through the Interdisciplinary Enterprise" (1991) that "[i]n interdisciplinary efforts, participants must have an eye toward the holistic complex of interrelationships" (p. 341). Brian S. Turner (1990) takes the position in "The Interdisciplinary Curriculum: From Social Medicine to Postmodernism" that, "[g]iven the complexity of health issues, the approach of medical and sciences *ought* to be interdisciplinary" (p. 496, author emphasis). And Grant Cornwell and Eve Stoddard (1994) insist in "Things Fall Together: A Critique of Multicultural Curricular Reform" that "[c]ultures, in their ever-shifting interactions and complexities, need to be both researched and taught from interdisciplinary perspectives" (p. 519). While most of these authors do not use *complex* or *complexity* in the technical sense employed in this article, the frequent non-technical use of the terms (of which these examples are only a few) suggests at least roughly parallel lines of thought.

The Interdisciplinary Process

Klein (1990)

Before drawing on complex systems theory to rationalize and inform interdisciplinary method, we need to look closely at the interdisciplinary process underlying that method. There is widespread agreement that interdisciplinarity is essentially a process. Likewise, there is general, but vague agreement on the steps in the process, though scholars disagree whether the process is linear and sequential, or looped and flexible. Julie Klein (1990) took a first stab at specifying the steps in *Interdisciplinarity: History, Theory, and Practice*:

- *defining* the problem [question, topic, issue];
- *determining* all knowledge needs, including appropriate disciplinary representatives and consultants, as well as relevant models, traditions, and literatures;
- *developing* an integrative framework and appropriate questions to be investigated;
- *specifying* particular studies to be undertaken;
- *engaging* in "role negotiation" (in teamwork);
- *gathering* all current knowledge and *searching* for new information;
- *resolving* disciplinary conflicts by working toward a common vocabulary (and focusing on reciprocal learning in teamwork);
- *building* and *maintaining* communication through integrative techniques;
- *collating* all contributions and *evaluating* their adequacy, relevancy, and adaptability;
- *integrating* the individual pieces to determine a pattern of mutual relatedness and relevancy;
- *confirming or disconfirming* the proposed solution [answer]; and
- *deciding* about future management or disposition of the task/project/patient/curriculum. (pp.188-189)[3]

In keeping with the focus of the book, these steps are a blend of theory and practice, folding interpersonal issues of interdisciplinary teams into conceptual issues of interdisciplinary epistemology.

Newell Version

My candidates for the steps in the interdisciplinary process are abstracted from messy issues of teamwork—there are, after all, solo interdisciplinarians—and they are categorized according to the Klein and

Newell (1997) definition of interdisciplinarity.

A. Drawing on disciplinary perspectives:

- *defining* the problem (question, topic, issue);
- *determining* relevant disciplines (interdisciplines, schools of thought);
- *developing* working command of relevant concepts, theories, methods of each discipline;
- *gathering* all current disciplinary knowledge and *searching* for new information;
- *studying* the problem from the perspective of each discipline; and
- *generating* disciplinary insights into the problem.

B. Integrating their insights through construction of a more comprehensive perspective:

- *identifying* conflicts in insights by using disciplines to illuminate each other's assumptions, or by looking for different terms with common meanings, or terms with different meanings;
- *evaluating* assumptions and terminology in the context of the specific problem;
- *resolving* conflicts by working towards a common vocabulary and set of assumptions;
- *creating* common ground;
- *constructing* a new understanding of the problem;
- *producing* a model (metaphor, theme) that captures the new understanding; and
- *testing* the understanding by attempting to solve the problem.

Theoretical Rationale

While most interdisciplinarians would probably feel comfortable with either list, and not particularly care which one they use, neither is grounded in an epistemology of interdisciplinarity. Both are drawn from observing the activities of practicing interdisciplinarians without the support of any theoretical rationale. But what if the current practice of interdisciplinarity is flawed or essentially arbitrary? What if some steps are inappropriate? Worse, what if the entire process is fundamentally misguided? We may sense that the process is sound, but it would be reassuring to have a solid theoretical basis.

The thesis of this paper, that interdisciplinarity is necessitated by complex systems, suggests a procedure for testing the appropriateness of the steps that have come to be included in the interdisciplinary process. Since the process is a response to the nature of the reality being studied, it should reflect what we know about the characteristics of complex systems. Each step in the interdisciplinary process should have some analog in complex systems theory. A step-by-step comparison with the Newell version follows.

Interdisciplinary Process and Complex Systems

Drawing on Disciplinary Perspectives

To understand an interdisciplinary problem in complex systems terms, let's return to one of the opening examples. Acid rain is produced by human economic activity driven by a global economic and financial system, sanctioned by a political system, and embedded in a culture and history. That activity interacts with the physical environment through a series of cascading meteorological, chemical, biological, and physical events which operate through an interacting set of geological, chemical, and hydrological cycles to produce harmful effects to a variety of human objects and activities and to ecosystems, as well as to the wash hanging in your backyard and the statue in the town square. The disciplinary systems, the environment, events, cycles, objects and activities, and ecosystems can all be fruitfully thought of as components or sub-systems of a larger complex system. Acid rain is an overall pattern of behavior modeled by that complex system. The challenge facing the interdisciplinarian is to understand the problem of acid rain within the context of the pattern of behavior and to propose solutions consistent with that pattern.

Defining

Since each discipline focuses on the behavior of a particular sub-system modeling one facet of reality, its very definition of the problem (indeed, its understanding of whether there even *is* a problem) is shaped by the context and scale of its sub-system. Economists see acid rain as a problem of externalities, political scientists as a regulatory problem, and engineers as a design problem. Because the larger system is complex, the portion of the overall behavioral pattern one discipline observes in its local context may be quite different from what another discipline sees. The engineer may decide there is nothing wrong with the design of a power plant and criticize instead the economic decision to burn high- instead of low-sulfur coal. The task of 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.

Determining

Over time, each discipline has developed tools suited to the study of phenomena modeled by a particular sub-system. The challenge to interdisciplinarians in selecting disciplines and other perspectives from which to draw is to figure out which sub-systems contribute substantially to the overall pattern of behavior they wish to study using a complex system. To some extent, that challenge can be met by checking each discipline to see if it already has a literature on that topic, or by asking faculty colleagues in each department if they see a way their discipline could contribute to the study. One might not immediately think of anthropology, for example, as having much to offer to a study of acid rain. But one's colleague in that department will know that cultural materialism provides a general framework for thinking about the human-environment interface, especially the ways economic practices and technology lead to changes in the ecosystem. Because the overall system is complex, however, the contributions of individual sub-systems to the behavioral pattern of the overall system may not be obvious even to the disciplinarians who study them. Thus, interdisciplinarians are well advised to err on the side of inclusiveness (at least in their initial inquiries) and to be alert for nonlinear connections that may have escaped attention.

Developing and *Gathering*

Interdisciplinarians need not become experts in the disciplines they utilize. Beyond a general feel for the perspective of the discipline, they merely need sufficient command of its relevant portions to illuminate the specific features of that particular complex system. To study the physics of acid rain, for example, they need to understand basic thermodynamic principles underlying the operation of an electrical-generating power plant, but they are unlikely to require an understanding of sub-atomic physics. Since no two complex systems are alike, interdisciplinarians typically need to learn something new about a discipline each time they make use of it. Again, the complexity of the system under study means that unexpected portions of a discipline may prove useful. For that reason, it is essential that interdisciplinarians develop a feel for the discipline's perspective, so they can be alert to its other potential contributions to their study.

Searching

Disciplines tend to focus narrowly on issues that appear interesting within the context of that sub-system. When interdisciplinarians attempt to draw on a discipline to study an issue of interest in the context of the system as a whole, they may find that more research must be completed to apply the general perspective and relevant specific concepts, theories, and methods of that discipline. When acid rain became defined in the 1970s as a systemic problem in the United States, for example, ecologists had done little research on the effects of high-pH clouds on mountain forests and the entire sub-field of environmental economics had to be developed.

Much of the new knowledge required by interdisciplinarians is unlikely to ever be generated by the disciplines, however. The distinctly interdisciplinary research challenge is to identify and study the typically nonlinear linkages between disciplinary sub-systems. For example, just what are the connections between the economic and political sub-systems studied by social scientists and the atmospheric and biological sub-systems studied by natural scientists that combine to produce acid rain? Since those connections fall outside the purview of every discipline, their exploration is left to interdisciplinarians.

Generating

The goal in applying each discipline is to develop an understanding of how the behavioral pattern produced by the relevant portion of the sub-system it studies is related to its components and their relationships. For example, the application of economics to the study of acid rain reveals the behavior of that portion of the economic system that drives decisions about the use of coal in power plants. And the application of the interdiscipline of political economy reveals some linkages that connect the economic and political systems.

Integrating Disciplinary Insights

So far, the application of complex systems theory has been validating the steps in the interdisciplinary process (and thus the thesis of this article). That validation alone is worthwhile because it provides a rationale for what skeptics can otherwise criticize as an arbitrary process. With the remaining steps, however, we enter the portion of the interdisciplinary process that has always been something of a mystery, namely integration. Most of us can point to examples (probably only a few) of successful interdisciplinary integration; we may even have experienced it ourselves. But no one I have talked to or read (including my own writings) has been able to explain clearly how to integrate disciplinary insights into a comprehensive understanding. We are not even clear on exactly what is *meant* by integration (Newell, 1998, pp.

547-550). I believe complex systems theory holds the potential not only for validating the remaining steps in the interdisciplinary process, but also for assisting us in conceptualizing and evaluating interdisciplinary integration. As a result, I believe the theory can help us become better interdisciplinarians. With that in mind, let's proceed.

Identifying and *Evaluating*

Since each discipline has been developed to illuminate a different, particular facet of reality, its assumptions should reflect (however imperfectly) the principles governing that facet. Otherwise, the discipline would have proven ineffectual and eventually been discarded. Those assumptions should (and do) vary from discipline to discipline since the behavior of a complex system varies with locale (i.e., place and local knowledge matter). Thus the principles underlying that behavior vary as well. To identify the principles by which a particular facet operates, the interdisciplinarian probes the assumptions of the discipline that has demonstrated utility in understanding that facet. Since assumptions tend to be invisible when everyone shares them, the most effective way to probe the assumptions of one discipline is to scrutinize it through another discipline. In the study of acid rain, for example, when the biological concept of carrying capacity is scrutinized from the perspective of economics, its unstated assumption of constant technology is revealed. When classic theories of economic growth are examined from a biological perspective, their assumption of unlimited natural resources becomes evident.

Complex systems theory brings out the under-recognized need for interdisciplinarians to scrutinize and frequently modify terminology used by contributing disciplines. Technical terms are defined by a discipline to bring out the characteristics of a component or relationship relevant to its subsystem. When seen in the larger context of the entire complex system, additional (perhaps even different) characteristics are likely to become relevant. After all, they are now seen as contributing to a different behavioral pattern. Definitions become especially important when comparing insights from different disciplines. When the same term is used by two disciplines, interdisciplinarians need to look closely for differences in connotation if not denotation. In the process of studying acid rain, for example, the careful interdisciplinarian will discover that "efficiency" has quite different meanings for biologists and physicists (energy out/energy in), economists (dollars out/dollars in), and political scientists (influence exerted/political capital expended). They should also be alert to unrecognized common features reflected in different terms.

Resolving and *Constructing*

The task of interdisciplinary integration involves two interrelated challenges: recognizing the overall behavioral 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 sub-systems. Integration necessitates working backward from the phenomenon and forward from the sub-systems studied by different disciplines. That integrative process is anything but linear. A proposed pattern is tested first against one criterion, then the other, then revised and re-tested. Thus, interdisciplinary integration is driven by the tension between disciplinary insights and phenomenological pattern.

The process of relating the overall pattern of behavior to the behavior of sub-systems and their components is challenging for any system, since the whole is different from the sum of its parts. Even more challenging is the construction of an overall pattern of behavior for a system that is complex. Were it not for the observable pattern of behavior of the phenomenon modeled by that complex system, the task would be impossible. As it is, interdisciplinarians know what the system's pattern should look like. Their task is to understand why the behavior of the system exhibits that pattern, given the structure of the system and the behavioral patterns of its sub-systems.

In the process of oscillation between sub-systems and overall pattern, the terminology and assumptions of contributing disciplines are adjusted to the larger understanding as it is developed with input from their terms and assumptions. In practical terms, this means that disciplinary terms and assumptions need to be modified so they are responsive both to the disciplinary perspective on the behavior pattern of a particular sub-system and to the interdisciplinary understanding of the complex system as a whole (and thus the behavior pattern of the phenomenon it models). The trick is to modify terms and assumptions as little as possible, while still creating adequate common ground on which to construct a coherent understanding.

Creating

The creation of common ground involves the modification or reinterpretation of components or relationships from different disciplines to bring out their commonalties so that linkages can be identified between sub-systems. It is my contention that the process of creating common ground, while requiring creativity, need not be thought of as mysterious or nebulous. Newell (2000) identifies a number of techniques of interdisciplinary integration that

I believe have widespread applicability across a range of complex systems. These include: redefinition of terms from different disciplines to bring out a commonality; extension of the meaning or range of application of a concept; creation of a continuum of meaning along which concepts from different disciplines can be arrayed; transformation of opposing disciplinary axioms into a continuous variable; rearrangement of sub-systems to bring out interrelationships such as facilitation, encapsulation, or absorption; and recognition of joint dependent variables.

An important implication of the complex systems understanding of integration is that some *common-ground* solutions are better than others. The best solution minimizes the change in disciplinary assumptions while still creating an adequate base on which to build a comprehensive understanding of the behavior pattern of the system. The change cannot be arbitrary, but must respond to the difference in context. Similarly, the best *systemic pattern* solution is as responsive as possible to each discipline's perspective while still achieving sufficient coherence to hold the system together and being faithful to the behavioral pattern of the phenomenon under study.

Producing

The more comprehensive understanding produced by interdisciplinary study is an understanding of how the behavioral pattern of the system comes about from its constituent parts. That behavioral pattern has a kind of unity and coherence, even though the pattern is only quasi-stable, dynamic, and evolving. The essence of the unity and coherence of the pattern can sometimes be captured in a metaphor or theme. The best metaphor or theme captures the defining characteristics of the new understanding without denying the conflict that underlies it. Successful integration produces a pattern that closely reflects the known behavior of the various sub-systems (and their components and relationships) as well as the behavior of the phenomenon under investigation. A complex systems understanding developed through the interdisciplinary process will see acid rain, for example, as a coherent but evolving phenomenon that is *at once* physical, biological, economic, and political. While that understanding must be firmly grounded in the insights of its subsystems, it will be qualitatively different. Concepts of efficiency, for example, that are useful in the context of its various sub-systems, make little sense in the overall behavior pattern of a complex system where positive feedback loops and nonlinear linkages mean that small changes can have large effects.

Testing

The proof of successful integration is pragmatic. In the case of acid rain, the test is whether policy can be constructed on the basis of the resulting understanding that helps solve the problem. In general, can one act effectively on the basis of the more comprehensive understanding of the complex system? Better integration produces more accurate or complete understanding and makes more effective action possible.

Unfortunately, the operational problem with testing interdisciplinary understanding is that the very notion of empirical validation is grounded in a linear, pre-complex systems world in which effects are proportionate to causes. Remember that the evolutionary path of a complex system is also characterized by nonlinearity. Thus an acid rain policy developed through the interdisciplinary process can propose a modest intervention that turns out to produce large and unexpected results. Still, we live in a world characterized by complexity and we need to act. An interdisciplinary understanding provides a more effective basis for action than do the separate and more parochial understandings of the disciplines. The recognition of complexity should not lead us to throw up our hands, but to develop humility as well as interdisciplinarity.

Conclusion

Taken together, these applications of complex systems theory offer us a way to conceptualize the interdisciplinary process in general and integration in particular. Moreover, complex systems theory offers guidance for criteria for carrying out and then evaluating the success of each integrative step. If I am right, that complex systems theory indeed permits us to visualize each step in the integrative process and to determine how well we integrated, it will have amply demonstrated its usefulness for interdisciplinarians. If it also offers a convincing validation of the interdisciplinary process, it deserves a central role in interdisciplinary epistemology. In either case, interdisciplinarians are well advised to keep an eye on the complex systems literature.

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Biographical note: William Newell was founding president of AIS in 1979 and has served since 1983—first, as secretary-treasurer and newsletter editor and then, as executive director. He compiled *Interdisciplinary Undergraduate Programs: A Directory for AIS*, in 1986, and edited the AIS-sponsored anthology, *Interdisciplinarity: Essays from the Literature,* in 1998. He has published over 25 articles and chapters on interdisciplinary studies; guest edited two journals; and served over 70 times as consultant or external evaluator to colleges and universities in the United States, Canada, and New Zealand. He directs the Institute in Integrative Studies and, in his spare time, is a professor in the School of Interdisciplinary Studies at Miami University.

Notes

1. For a review of the "base domains" of complexity, see Göktug Morçöl, (2000b) especially Table 1: Domains, Metaphors, Assumptions, and Entailments, pp. 51-52. To give the reader a sense of the scope of the problem, here are some of the books, beyond those cited, that I have consulted for this paper: Bak, P. (1996). *How nature works*; Coveney, P., and Highfield, R. (1995). *Frontiers of complexity*; Flood, R. (1999). *Rethinking the fifth discipline;* Heylighen, F., Bollen, J., and Riegler, A. (Eds.). (1999). *The evolution of complexity;* Jervis, R. (1997). *System effects;* King, I. (2000). *Social science and complexity;* Marion, R. (1999). *The edge of organization*; Prigogine, I., and Stengers, I. (1984). *Order out of chaos*.
2. This distinction was suggested to me by J. Linn Mackey.
3. Klein numbered this series in clusters; I have quoted accurately but bulleted the items and added the emphasis.

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