The Non-Science Science of Complexity Theory: Towards a New Scientific Construction of Nature

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Introduction

In pre-Enlightenment, nature and people were seen as being the determined creation of a divine God. The Aristotelian-Christian world view believed that the world was hierarchically ordered wherein everything had a rightful place and purpose in a divinely created and ordered universe. The Enlightenment challenged this view asserting that the world existed as part of a system that obeyed "natural laws." What was fundamental to the scientific view of the Enlightenment was the strong link it made between reason (represented by humanity) and nature (everything outside of the socio-cultural realm). The Enlightenment concept of nature stressed that the universe was a mechanical system comprised of matter that was in constant motion, which followed the physical laws of nature. It was believed that through reason, individuals and society could become versed in the "laws of nature" which would lead to a peaceful and harmonic co-existence with nature and the universal order (Seidman, 1994:20-21; Touraine, 1995:15).

The influences of the Enlightenment still remain very much alive today. While the ideals of the Enlightenment are no longer a bound, unified concept, the principle strength of modernity still lies in the adage "trust in science." Instrumental reason and modernization are themselves both the construction of a rationalist image of the world that attempts to integrate humanity with nature (Seidman, 1994:6, 25-26; Touraine, 1995:28-33).

With new theoretical developments like quantum mechanics, string theory, chaos theory, and complexity theory, many of the assumptions posited by Enlightenment thinkers about nature are being challenged in much the same way that the Enlightenment challenged the Aristotelian-Christian view of nature. Complexity theory refutes the Enlightenment and modernist view that the natural world is an ordered, mechanistic system. Rather than being simply ordered and mechanistic, complexity theory suggests that all complex systems, whether natural or cultural, are also disordered, chaotic, fluid, and unpredictable. This new scientific interpretation of the world challenges traditional scientific assumptions and models of nature and society. The following paper will provide a general outline of complexity theory and demonstrate how this new paradigm challenges the modernist constructions of nature as an ordered, mechanistic environment with a more desirable model that is dynamic, fluid, and interdependent.

Complexity Theory

Complexity theory developed out of the surrounding research on chaos theory. While chaos theory focuses on the hidden order that resides within chaotic systems, complexity theory is concerned with how ordered, complex systems spontaneously emerge out of chaotic systems. This spontaneous emergence of ordered, complex systems is often referred to as *self-organization*, or emergent complexity. What makes complexity theory unique then, unlike chaos theory, is its ability to account for structure, coherence, and the self-organizing process of complex systems. Complex systems then, are not merely *complicated*,[1] static objects, but non-linear, spontaneous, disordered, self-organizing, adaptive systems (Ditto & Pecora, 1993:78-79; Hayles, 1991:12; Waldrop, 1992:11-12). The notion of 'adaptiveness' is an important one. Allen points out how adaptability is central to complexity in the following passage:

> *It is about 'adaptability', and the capacity to become aware that circumstances have changed and to produce new solutions. Not only that, it is also true that this ability to produce innovation and change will drive circumstances of others and drive evolution itself, favouring individuals capable of dealing with change, and eliminating those that are incapable (1994: 584).*

Rather than passively responding to events, complex systems actively attempt to turn circumstances to their advantage. It is this innovative awareness and reflexive characteristic that gives complex systems their dynamism and life-like quality.

The foundation for complexity arose out of the second law of thermodynamics which states that in a closed system, entropy (S) – a function of absolute temperature – always tends to increase. In other words, in every real heat exchange a proportion of heat is always lost to 'useful' purposes, also known as the *universal tendency toward dissipation*. In this model, heat is constantly dissipated until the universe expends its entire heat reserves. In a system of constant dissipation the mean temperature would eventually stabilize at just above absolute zero, and all life would cease to exist – this teleology is often referred to as *heat death*. The idea that the universe is in a constant state of approaching zero, and in a downward spiral that increasingly becomes disordered as heat dissipates could not be further from the truth (Hayles, 1991:12-14). Prigogine and others have posited entropy as the engine that drives the world to increased complexity rather than disorder. They argue that in systems far from equilibrium, entropy production is so high that any decreases in entropy can take place without contradicting the second law, and that under certain circumstances this same mechanism can allow systems to engage in spontaneous self-organization (Prigogine, 1984:117-122, 272-277, 295-297). Entropic disorder, then, plays a constructive role in creating order which suggests that the universe has the capacity to renew itself.

After Prigogine, Gunzig, and Geheniau linked entropy to cosmology, the theory of complexity and self-organization began to be applied to evolutionary biology, economics, and other systems that shared similar dynamics (1984:115). Complexity is found in dynamic, nonlinear systems and can explain the structure, coherence, and self-organization of complex systems which exist *at the edge of chaos* (a phase space where life is afforded enough stability to sustain itself and enough creativity to be adaptive) where dynamic systems have the ability to balance order and chaos simultaneously.[2] This balance lies within a system which is never quite stable and yet never quite turbulent (Hayles, 1991:13-14; Prigogine, 1984:115-117; Waldrop, 1992:11-12, 293). As Waldrop has described it, "the edge of chaos is the constant shifting battle zone between stagnation and anarchy, the one place where complex systems can be spontaneous, adaptive, and alive" (1992:12).

The edge of chaos is a position or 'phase transition' between two extremes and it is in this phase transition that one finds complexity. While a first-order phase transition refers to the sharp and precise point or moment of change from one state to another, second-order phase transition, the kind found in complexity, occurs much less abruptly. At the equilibrium of a second-order transition, order and chaos are balanced and intertwined in a complex and changing flux (Waldrop, 1992:229-230). Langton developed three examples that illustrate a state of phase transition:

Figure 1

Cellular Automata Classes:
I & II → IV → III

Dynamical Systems:
Order → Complexity → Chaos

Matter:
Solid → Phase Transition → Fluid

It is in phase transition that information can be both stored and transmitted. In the example of the cellular automata classes, structures governed by rules I and II could store data, but would be too static or ordered to transmit the information; similarly, data in a chaotic class III environment would get lost amidst the noise (uncoded matter-energy).[3] Langton concluded that only a class IV environment can provide the stability necessary to store information and enough fluidity to transmit signals across arbitrary distances. Thus, the rules necessary for the storage and transmission of information are those that reside in the second order phase transition, at the edge of chaos (Waldrop, 1992:231-232; Wilden, 1980:xix).

What is fundamental to the process of increased complexity and the emergence of spontaneous self-organization is the role of the agent. In complexity, systems are made up of a network of agents that act in parallel. It is important, here, to think of agents as a plurality. That is, agents can either be individuals or 'collectivities'. For example, households, cities, provinces, or countries can all be seen as agents depending on what level or system one is examining. Regardless of the category though, the environment of the agent is produced through interactions with other agents within a given system. That is, agents are constantly acting and reacting to what other agents are doing in the system. Because of this, the environment is always dynamic, fluid, and unfixed. Moreover, the agents themselves have to be dispersed (as opposed to being centralized) if there is to be any coherent behaviour in the system. What is central to complexity theory is the notion that coherent behaviour can only arise out of competition and cooperation among agents themselves (Waldrop, 1992:145).

In any adaptive, complex system there are many levels of organization wherein agents at one level serve as the "building blocks" for agents at a higher level of organization. For instance, individual workers make up a department, several departments make up a division, and several divisions make up a company, and so forth. What is of importance here is that adaptive, complex systems continually revise and reorder building blocks as each level of organization gains more experience similar to the modification, reorganization, and adaptation that occurs in the process of evolution. Whether we are speaking of cells, neurons, organisms, politics, or economics, the processes of learning, evolving, and adapting are the same within each level of organization (Waldrop, 1992:145-146).

An adaptive agent will exploit certain environments to fill niches which exist in all complex, adaptive systems. If an agent already has an adaptive trait that corresponds to a particular niche, it will exploit that niche in order to fill it. Further, when one niche is filled, other niches will open up for new symbiotic partnerships. Thus, new opportunities are constantly being created. As a result, a complex system can never reach equilibrium because it is always unfolding, becoming, and in transition. In other words, complex systems are characterized by perpetual novelty. If a system ever reached the point of equilibrium, it would become static and stable which would result in its death. As such, agents can never maximize their utility or optimize their fitness because the possibilities are too diverse to ever find the optimum. The agent can only change, improve, and adapt relative to the behaviours of other agents in the system (Waldrop, 1992:147).

Inter/dependent Hierarchies

The idea that adaptive, complex systems are multi-layered, interlinked levels of organization emphasizes their adherence to hierarchical properties rather than being a dualism or binary opposition. Wilden has poignantly observed that many of the assumptions about oppositions are often unfounded and *imaginary*.[4] For example, the relationship between nature and culture might be described as an opposition; however, this 'oppositional' relationship only exists as an imaginary metaphor. To describe nature and culture as opposites does not accurately depict the relationship within the context it was intended ($ab = xy$). Rather than opposites, the relationship between nature and culture can more accurately be described as a dependent hierarchy. That is, culture is necessarily dependent on nature, but nature is not dependent on culture ($ab\ xy$). Thus, any relationship between levels in a hierarchy, whether they are contradictory or not, does not constitute an opposition. Such 'oppositional' metaphors, then, do not provide accurate descriptions of natural relationships as much as they represent deeply rooted social values. Wilden notes that while many oppositions are imaginary representations of real relations, 'real' oppositions do exist. In a true relation of opposition, both terms or systems must be interchangeable without affecting the relationship between them (Wilden, 1981:4-9). That is, they must be commutative and of the same logical type ($xy = yx$).

By hierarchy, I am referring to the *near-decomposability* of different orders of organization and interaction. If we think of a set of Chinese boxes whereby opening any given box reveals a smaller set of boxes, and opening any one of those reveals yet another set of boxes, and so on, then we can understand the notion of multiple levels of organization and systems. The direction of hierarchies in adaptive, complex systems, however, are contrary to the traditional model of hierarchies which are ordered top down.[5] Hierarchies in complex systems are based on the idea of building blocks which makes higher levels dependent on lower ones. This inversion promotes "grass roots" or bottom-up organization. Moreover, as one level builds on top of the next, each new level of organization becomes increasingly more complex (O'Connor, 1994:611; Waldrop, 1992:333).

The possible activities of a particular system or subsystem, however, are limited and constrained in dependent hierarchies. An example of this can be seen in Wilden's use of the *extinction rule.* The extinction rule can be used to orientate a complex, dependent hierarchy. By eliminating different levels of the hierarchy, we can determine which levels are necessary and which will become extinct if removed. For instance, if we use inorganic, organic, and socio-cultural categories, the hierarchy can be illustrated as follows:

Figure 2

inorganic nature

organic nature

socio-cultural

If we now apply the rule of extinction, it becomes apparent that if we eliminate either the inorganic or organic environments, the socio-cultural environment will cease to exist. Moreover, if we only eliminate the inorganic environment, then neither the organic nor socio-cultural environments can exist. However, if we eliminate the socio-cultural environment, the organic and inorganic environments will still thrive (Wilden, 1980:xxxv; 1981:3-4).

Not only is each environment dependent on the one before it, but each environment is critical in the formation of the next. That is, each time a new adaptive self-organizing system emerges out of the last, it becomes increasingly more complex. This, however, does not mean that higher levels of organization can not affect or impact on lower systems. Take for example, the impact that socio-cultural systems and human behaviour have had on both organic and inorganic systems. Changes to lower systems that are the by-product of human behaviour will also change the patterns of those same human systems as they are forced to readapt and modify to changes in the organic and inorganic environments.[6] That is, because they are dependent, they are necessarily interdependent. The belief that there is an autonomy of system components which have distinctive behaviour and creativity no longer holds true in complexity. That is, the properties that an element displays are not seen as being intrinsic to the object itself. Rather, discernible components in conjunction with their properties emerge within a collective regime of activity. Both *the objects and properties are the co-effects of the totality of their interactions.* Thus, a single element can only be understood in terms of its inter-relation and inter-being with the rest of what it is (O'Connor, 1994:611-612; Waldrop, 1992:145, 176, 349).

In adaptive, complex systems the relations and interactions *between* interdependent parts are of greater importance than the individual agent itself. In other words, it is the interaction and connections between individuals rather than the individuals themselves that are responsible for the creation, maintenance, and renewal of systems and structures. However, under certain circumstances minute inputs or minor fluctuations in a system may be amplified which can result in systemic change. Such systemic and structural change can be facilitated by an individual through replication errors and mutations which become amplified by positive feedback (as reflected in the *butterfly effect*[7]). Thus, an individual agent can play a fundamental role in creating and changing systems. The control of networks and complex systems, however, is generally dispersed rather than being centralized. It is in the distributive nature of control and bottom-up organization of complex systems which makes them impossible to specify and predict. Complexity theory, then, is a dynamic model that allows for the innovative and creative emergence of new levels of complexity and spontaneous self-organization (Waldrop, 1992:348-350).

Scientism Revisited?

While complexity theory deconstructs the modernist notion that there is an element of control and certainty in science, it also positions itself as a totalizing theory. However, as poststructural critiques of modernity have demonstrated, there is no universality that marks the world – rather, the world is made up of differences (Seidman, 1994:231). While complexity theory asserts a totality, it is a totality of difference and ambiguity. The metaphor of multidimensional phase space (see *Figure 1*) allows for the plurality of legitimate perspectives which are the foundation of diversity. Thus, while complexity is a theory of unity (i.e., *all* complex systems are adaptive, unpredictable, and dynamic), it simultaneously challenges the Enlightenment assumptions that have either sought or imposed the ideals of foundationalism and "universal truth." Unlike the Enlightenment then, complexity is both unifying and fragmenting. It is in emergent complexity were the contradiction between hegemonic reductionism and fragmented relativism can be resolved[8] (Funtowicz & Ravetz, 1994:569). The danger lies in the perception that complexity is, in and of itself, a totality without recognizing that such totality necessarily involves change, difference, chaos, and fragmentation.

The idea that complexity is an all encompassing theory which can be used as an explanatory model for biological evolution, consciousness, weather patterns, earthquakes, revolutions, social change, and the stock market also reflects something about its links to the Enlightenment (Appignanesi et.al., 1995:109). That is, there is a propensity to invest complexity theory with the modernist ideal of positivism. The term positivism, here, refers to the social/scientific search for a grand organizing principle that unifies the world (Bullock et.al., 1988:669). In much of the literature there is a positivist subtext that states, "if we could only know everything we could solve the world's problems." However, the subtext of positivism is contradicted by the very nature of complexity. That is, you cannot "know everything" in a world that is unpredictable and has no certainty. Thus, despite positivist overtones, complexity itself cannot sustain a prolonged dialogue with positivist ideals.

It might be argued that by ordering systems in a hierarchy of increased complexity, levels that are more complex might be interpreted as being superior. However, the notion that one level is superior over another does not account for the dependency that "higher" complex levels have on "lower" levels. Moreover, because lower levels act as the general environment for higher levels, the lower levels are broader, more adaptable than are higher levels (see *Figure 2*). It is in the lower levels of complexity were change is generally initiated from. Thus, it could be just as easily argued that lower levels of complexity are superior to higher levels. However, because levels are interconnected, any level that is relegated to "subordination" can potentially set off a chain reaction that will result in systemic change to other levels in the system.[9] Because there is no distinction between the initiators and receptors in an interlocking network, any action that favours a particular group or order faces the unpredictable adaptation of the overall system. Thus, any action (intentional or unintentional) may set in motion a chain of events that will form different patterns for the initiator to adjust to (Waldrop, 1992:333). Thus, illustrating levels of complexity hierarchically does not infer a hierarchy of dominance, but of complexification.

Complexity theory should not be confused with earlier, more static models like 'ordinary complexity' and systems theory. In models of 'ordinary' complexity or systems theory, behaviours are explained as mechanisms that serve a functional teleology. In biological systems, for instance, the goal is growth and survival. The normal state of such a system is a diversity of elements that coexist in a complementary environment of cooperation and competition. By contrast, emergent complex systems cannot be fully explained through functional or mechanical means because elements of the system possess individuality, 'intentionality', consciousness, foresight, purpose, and symbolic representation. Thus, any attempt to reduce natural, cultural, and societal systems exclusively to the realm of ordinary complexity can result in unrealistic empirical models. Furthermore, ordinary, mechanistic complexity cannot explain the concept of novelty. In emergent complexity, however, continuous novelty is considered a characteristic property. With its ability to deal with novelty, emergent complexity better reflects the dynamic flux of both natural and cultural systems (Waldrop, 1992:242; Funtowicz & Ravetz, 1994:570-571).

Assuming 'survival' or adaptability as the *only* thing that counts in a system is both 'reductionistic' and dangerous. Mechanistic scientific world views blame and punish the weak which leads to a logic that goes beyond morality similar to that found in eugenics. Emergent, complex self-organization can be applied as a heuristic device to deal with the more technical context of systems theory. However, any description of systems and relations, such as *competition*, necessarily structures our perceptions, concepts, and research. Whether we are speaking in terms of ordinary or emergent complexity, researchers must be aware of their own paradigmatic biases to avoid imposing any interpretive authority onto a truly complex system (Funtowicz & Ravetz, 1994:571, 580-581).

Conclusion

In summary, complexity theory can be described as the unpredictable and creative emergence of new types of complexity that occur in natural, cultural, and societal systems. Such creativity results in complex, ordered systems emerging out of order, disorder, and chaos. Generally, complex, adaptive self-organization takes place in a population of independent agents. Through the exchange and interaction of cooperation and competition, these agents become increasingly interdependent which results in the spontaneous emergence of new and creative structures. The emergence of novel structures not only raises a system's complexity to a higher level, but provides the foundation necessary for the emergence of yet another level of complexity. The agents in adaptive, complex systems maybe constituted by any individual, group, collectivity, or population which makes up, or is organized around a particular system or structure.

Since the Enlightenment, science has attempted to understand, analyze, and explain nature as an ordered, mechanistic environment. The link between modernity, science, and rationality are tightly interwoven as are their influences to the way we perceive nature. Mounting critiques against modernity and the ideals of scientism have begun to deconstruct the authority of science and with it, the concepts of Enlightenment rationality, objectivity, and "progress." Modernity has left behind a legacy that is familiar to most in environmental studies and activism: over consumption, linear progress, unlimited economic growth, managing eco-systems, toxic and carcinogenic pollutants, nuclear technology, global warming, and the depletion of the ozone have all been linked directly or indirectly to modernist ideology. However, with the benefit of history and hindsight, we are increasingly becoming aware that nature (in its broadest sense) is a dynamic, interdependent, non-linear system of ebbs and flows. The emergence of complexity theory and self-organization reflects not only a historical shift in scientific discourse, but a new interpretation of the natural world. It is becoming increasingly evident that whether we are talking about molecules, neurons, species, ecosystems, or societies, there are fundamental similarities in the way they function – exhibiting order, disorder, chaos, reproduction, and change.

With the rise of complexity theory, the scientific premises of foundationalism, universalism, objectivity, certainty, predictability, and order are being challenged and rethought. New theories in the physical and natural sciences are beginning to support the conclusions drawn by feminist, 'Afrocentric', and gay theories that have contested the separation between knowledge, values, and politics. New scientific theories are confirming that we no longer see the world "*as it is*" but in terms of ideological and subjective beliefs that reflect experiences and ethnocentric interests and values which themselves, are the products of a dynamic, complex cultural system (Seidman, 1994:312, 322). Complexity theory offers a model that can address the oppositional contradiction between nature and culture which has existed from pre-Enlightenment to late modernity. Rather than being an opposition, nature, in its totality, incorporates culture and society as part of an interdependent web of interaction. In many ways, complexity theory reaffirms the ideas of Gaia[10] and earlier works of people like Gregory Bateson. However, while the latest theories of complexity and self-organization are an improvement over the ordered nature of the Enlightenment or the biocentric modernist concept of *nature as "use-value,"* scientific constructions of nature themselves are subject to the laws of complexity. Thus, contemporary scientific paradigms will change, evolve, adapt and become more complex and with them, so too will our perceptions of nature.

Notes

1 An example of a *complicated* or simple system verses a complex system can be seen in the Koch Curve Construction. The Koch construction is a process that occurs when self-similar structures go through a feedback loop. For example, if we view an initiator as being a straight line (—)and then introduce a generator, say, a polygonal line (^) that sits on the initiator, and put it through a feedback loop which increases it by the factor of 4 through reproduction, we end up with is a complex pattern like that found on the edge of a snowflake (Peitgen et.al., 1992:91).

2 Emergent complexity posits the dialectical concept of "contradiction" as the key to understanding polar-opposite patterning. In doing so, emergent complexity can integrate seemingly paradoxical concepts such as *creative destruction* into a practical framework (Funtowicz & Ravetz, 1994:569).

3 Matter-energy that is coded is referred to as information, whereas matter-energy that is uncoded is referred to as noise (Wilden, 1980:xix).

4 Here, the term *imaginary* is based on Lacan's questioning of the relations between words and images. Lacan argues that meaning is created through oppositions. Within the realm of the binary, simple oppositions become, what Lacan calls, an "imaginary" reading of the signifier. In this instance, Lacan inverts the Saussurean formula which emphasizes the signifier (a meaningful form) over the signified (the concept that a form evokes). Lacan resists this model arguing that through opposition, the signified can determine the signifier (Ragland-Sullivan, 1991:49).

5 This contrasts sharply with the Christian hierarchy of pre-Enlightenment. Bateson notes that the traditional Christian hierarchy went downwards deductively which started from the superiority of 'man,' to the apes, and so on down to the 'simplest' creatures. As Bateson puts it, "This hierarchy was a set of deductive steps from the most perfect to the most crude or simple. And it was rigid. It was assumed that every species was unchanging" (1973:403). Even in modernity, biocentric hierarchies positioned 'man' at the top as master over all other realms. The following hierarchical inversion and "extinction rule" can be used to re-orientate those hierarchies that were erroneously asserted in the past (Wilden, 1981:333).

6 An example of this can be seen in a variety of human/nature relations. For instance, if global warming continues to increase due to sociocultural forces, then, at some point, cultural and societal behaviours will have to change, learn, evolve, and adapt to an altered biosphere if they are to continue to thrive.

7 The Butterfly Effect, or *sensitive dependence on initial conditions*, was first developed by Lorenz in the 1960's. The Butterfly Effect essentially states that errors and uncertainties multiply which creates a cascade effect. The actual term is derived from the example that if a butterfly stirs the air today in Peking, it can transform into a storm system the next month in New York (Gleick, 1987:8, 20-21).

8 Funtowicz and Ravetz cite the contradiction between reductionism and relativism as the postmodern condition (1994:569).

9 Complexity, if nothing else, is amoral. While initiating change that favours some over others may result in chaotic behaviour and a reordering of the system, it is just as likely that it could result in perpetuating the status-quo. In other words, there is no guarantee that the resulting adaptation of the overall system would be "fair" or just. Nothing, however, is static in a complex system, not even the status-quo – given time and world enough, the status-quo will eventually change.

10 Gaia, named after the Greek earth goddess, was developed by James Lovelock in the 1960's. Simply, Gaia states that the earth works as a single self-sustaining unit which is a living being with consciousness (Wall, 1994:78).

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