LEARNING AND COMPLEX ADAPTIVE SYSTEMS

(Article by Diana Stirling, Associate Researcher, Learning Development Institute)

EDITORIAL NOTE

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Learning and Complex Adaptive Systems

Diana Stirling

Part 1: Complex Adaptive Systems

Introduction to Complex Adaptive Systems

The science of complexity and complex adaptive systems has engendered a view of the beauty of self-organization which arises as a result of continual transformation, via nonlinear interactions, within and between co-creating systems. Through this lens, learning is seen as a continuous dynamic, the inevitable actualization of an innate biological potential. When the human individual is viewed as a complex adaptive system and learning is seen as an essential dynamic on which the system depends for survival, conscious learning is recognized as the tip of the learning iceberg. Still, might the concepts that drive complex adaptive systems be productively applied to formal learning situations?

This paper describes the basic characteristics of complex adaptive systems, contrasting complex systems with chaotic ones. A fundamental understanding of the characteristics of complex adaptive systems raises questions about whether these characteristics exist in conscious learning and asks, if they do, what the implications might be for designing effective learning environments and experiences. The exploration begins with an examination of the literature of complex adaptive systems, particularly the work of Kauffman, Holland, and Gell-Mann.

Before we begin, a caveat. The author is trained neither as a scientist nor as a mathematician. Therefore, the understanding expressed of these deep concepts may be limited. The utmost scrutiny is invited. In the overall conversation about the potential of complex science to lend insights into our world, this contribution may be one of many possible branches that, according to Kauffman, characterize responses to innovation, (14, 202). This is submitted, then, in the spirit and enthusiasm of the evolution of ideas that are the hallmarks of human endeavor.

A New Science

It is important to keep in mind that the field of complexity and complex systems is fairly new and there is certainly not consensus among researchers as to which models are the most successful and which must be modified or abandoned altogether. This is part of the appeal – researchers are in the midst of a lively exploration into questions for which, in the past, it seemed it would never be possible to find answers. Thus, debate about what properties are exhibited by complex systems, how such systems self-organize, and how self- organizing complex systems have come to exist in such great numbers, is in itself intriguing.

Another aspect of the creative confusion involved in studying complex systems is that the researchers studying them come from a variety of disciplines. Complexity can be found at the level of cellular systems, ecosystems, and social systems, and its effects can be seen in the global economy and the spread of disease. Thus, researchers are drawn to these ideas from widely diverse backgrounds and are working on a variety of problems. There is not a linear development of ideas involved; the researchers tend to focus on particular aspects of problems that pertain to their fields of interest. As a result, there is a profusion of terminology and there are sometimes different terms for the same or quite similar concepts.

Complexity and Chaos

In common usage, a distinction is seldom made between the terms complex and complicated. In fact, Webster's New World Dictionary lists *complicated* as the second definition of the word *complex*. However, in the science of complex adaptive systems, there is a significant difference between the two (Waldrop 11-12). Something that is complicated is intricate, but essentially static. In contrast, to say that a system is complex is to imply that it is involved in a dynamic process of interactions, a continual state of change. The interactions, more than the structure, distinguish a system as complex.

A complex system is said to exist on the border between order and chaos (Kauffman 26-29; Waldrop 12). However, such an image can be misleading, suggesting that there is a discrete boundary between static order and chaotic disorder, and that complexity stands there at a particular location. Rather than a particular place, though, complexity is a state of dynamic balance between the extremes of rigid order and chaotic disorder. As Waldrop explains, "…complex, self-organizing, adaptive systems possess a kind of dynamism that makes them qualitatively different from static objects such as computer chips or snowflakes, which are merely complicated" (11-12).

In some systems, the condition between order and chaos is called a *phase transition* (Johnson 111-112; Barabási 74-75). A phase transition is a critical point at which a system suddenly changes from one defined state to another. A common example of a phase transition occurs in the magnetization of ferromagnetic metal. In a state of disorder, each agent of the system (in this example, each atom) behaves individually. After the phase transition, all the atoms behave in precisely the same way, in unison. The system locks into stasis, the metal becomes magnetized. Near the critical juncture, the phase transition, the system vacillates between order and disorder; some agents of the system act independently while others join together to act in unison. The closer to the phase transition, the more ordered the system becomes, that is, the more agents join together behaviorally to act in unison.

Although complex adaptive systems and complex networks are not on their way to becoming entirely ordered and static, they exhibit many of the behaviors of systems that do undergo phase transitions. In particular, complex systems move between order and disorder, mixing elements of both in a dynamic process of adaptation. Knowledge of phase transitions has prompted Kauffman to describe complex systems as existing on the edge of chaos (26-29). A phase transition is a state of dynamic disequilibrium, and such disequilibrium is a hallmark of self-organizing complex systems. As Kelso explains, "Just as Galileo used an inclined plane (which he could manipulate) to understand the free fall of objects (which he could not), so this phase transition situation allows us to understand how coordinated actions are self-organized" (Dynamic Patterns: The Self-Organization of Brain and Behavior 53). Kelso examines the physiological mapping of physical coordination in the brain, but his comment can be said to apply to a variety of complex systems. Rigid order is fairly easy to understand. In contrast, the term chaos can be misleading. Like complex, chaos has a different meaning scientifically than its everyday usage suggests. While in ordinary conversation we refer to something as chaotic when we mean it is randomly disordered, scientifically speaking, chaotic disorder actually follows particular rules.

Characteristically, the slightest change in a chaotic system becomes magnified as the system moves forward in time, making it predictable in the short term, but impossible to predict in the long term. This is called "sensitive dependence on initial conditions" (Gleick 8). Typical examples of chaotic systems include cloud shapes and galactic clustering (Gleick 4). Another characteristic of chaotic systems is that "every point is a point of instability" (Strogatz 189), which means that any particular point in the system is vulnerable to a system-changing alteration. This instability combined with the exponential increase in slight changes over time results in a system which lacks resilience. In a chaotic system, the details are of the utmost importance.

There are other kinds of systems in which slight changes are not so significant. Although an ant colony may live for 15 years (Johnson 80-83), a single male ant lives only for one day, while a female ant lives for a maximum of one year. Not only that, but the colony itself matures, that is, an older colony behaves differently than a younger one. How can it be that, although the colony as a system matures, the components of the colony last only a fraction of the system's life span? This is not so different from the human body. You as an entity persist in spite of the fact that your cells are continually dying by the billions. Here, then, is a significant difference between complex systems and chaotic ones. As Johnson says, "The persistence of the whole over time –

the global behavior that outlasts any of its component parts – is one of the defining characteristics of complex systems" (82).

Complex Adaptive Systems

A complex adaptive system is a system which persists in spite of changes in the diverse individual components of which it is comprised, in which the interactions between those components are responsible for the persistence of the system, and in which the system itself engages in adaptation or learning (Holland 4). To say that a system is complex is to say that it vacillates between states of order and disorder, without succumbing to either state. To say that such a system adapts is to say that it responds to information by changing.

Such systems abound. Not only the ant colony and the human body as a whole, but various systems within the body such as the central nervous system and the immune system fall into this category. These are systems that persist in spite of the continual changes of individual components, maintaining coherence and adapting in response to a phenomenal amount of information throughout the lifetime of the organism in which they function (Holland 2-3).

Adaptation and Finding Excellent Solutions

Holland argues that adaptation itself builds complexity. Kauffman agrees, saying, "A living system must first be able to strike an internal compromise between malleability and stability. To survive in a variable environment, it must be stable, to be sure, but not so stable that it remains forever static" (Kauffman 73). Thus, these systems survive and thrive in an evolutionary, or more accurately, a co-evolutionary context.

Kauffman makes a case for the importance of the co-evolution of agents and their environments. As an agent changes, so does the environment, including other agents, and vice versa. Thus, agent and environment act as partners in the dance of evolution. This is easy to visualize when one thinks of the interrelationships in an ecosystem. But how does a particular agent "read" an environment of which it can only "see" a small part?

Kauffman argues that in a system in which there are many underlying conflicting constraints and interconnected variables, there exists an optimum size and number of "patches" or nonoverlapping domains which, acting locally by interacting only with the nearest neighbors, maintain the system in a state of maximum fitness with regard to evolution (Kauffman 256-257). Each agent in the system Kauffman models has access only to information in the local vicinity. (The reality is likely more complicated than this as, at the very least, many complex systems will be seen to be small-world networks. See Strogatz, *Exploring Complex Networks*, and Watts for more about this.) At the same time, each agent may be said to have a particular evolutionary goal of which it is unaware, but for which it is suited by its evolutionary history. The ultimate goal, of course, is survival. In having achieved survival up to the present moment, the agent as a system and the larger system(s) of which the agent is a part have engaged in a particular kind of learning that is inherent in adaptation. This learning involves maximizing the system's fitness with regard to the larger environment. Complex adaptive systems exist at a wide range of scales, from neurons to social systems. Therefore, the environment in which an agent acts may be incredibly tiny or it may be vast, from the human perspective. However, it seems likely that the larger system in which an agent participates is always beyond the comprehension of the individual agent within it. According to the theory of complex adaptive systems, the scale of complex systems is of little importance, except, perhaps, in relation to the time involved in the interactions or in the life of the system as a whole (see Gell-Mann 51-52).

Here the idea of maximum fitness means to be able to find excellent solutions to difficult problems rather than being able to find the best solutions (Kauffman 247-264). Generally speaking, finding the best solution may be impossible due to the multitude of possible solutions and the limited amount of time available for exploring them. Thus, Kauffman argues, it makes more evolutionary sense to devise strategies for finding excellent solutions at the possible expense of not finding the best or perfect ones.

Holland has worked extensively on this problem as well. He is well-known for having devised the genetic algorithm and the ECHO software for computer simulation of complex adaptive systems. The agents in Holland's computer simulations behave in much the same way that Kauffman describes, finding excellent solutions in the course of interacting with other agents and with the environment.

Gell-Mann explains just how these systems are able to evolve such excellent solutions. Gell-Mann's terminology differs from Holland's in that what Holland refers to as an "adaptive agent," within a complex system, Gell-Mann refers to as a complex adaptive system in its own right. Thus, in Gell-Mann's nomenclature, a complex adaptive system may (and often does) exist within another complex adaptive system and/or it may be associated with other complex adaptive systems that aggregate to form a larger complex adaptive system, and so on (51). Gell-Mann's description of the evolution of schemata in a complex adaptive system is elegant.

A complex adaptive system receives a stream of data about itself and its surroundings. In that stream, it identifies particular regularities and compresses them into a concise "schema," one of many possible ones related by mutation or substitution. In the presence of further data from the stream, the schema can supply descriptions of certain aspects of the real world, predictions of events that are to happen in the real world, and prescriptions for behavior of the complex adaptive system in the real world. In all these cases, there are real world consequences: the descriptions can turn out to be more accurate or less accurate, the predictions can turn out to be more reliable or less reliable, and the prescriptions for behavior can turn out to lead to favorable or unfavorable outcomes. All these consequences then feed back to exert "selection pressures" on the competition among various schemata, so that there is a strong tendency for more successful schemata to survive and for less successful ones to disappear or at least to be demoted in some sense (Gell-Mann 50).

Thus, a complex adaptive system: 1) interacts with the environment, 2) creates schemata, which are compressed and generalized regularities experienced in those interactions, 3) behaves in ways consistent with these schemata, and 4) incorporates feedback from the environment to modify and adapt its schemata for greater success. When Gell-Mann talks about "identifying" and "predicting," he is not necessarily referring to conscious events. For example, in the case of slime mold, which has no brain, the process is a purely biochemical one (Johnson 11-17).

Self-Organization in Complex Systems

The process by which a complex system achieves maximum fitness results in self-organization by the system, that is, agents acting locally, unaware of the extent of the larger system of which they are a part, generate larger patterns which result in the organization of the system as a whole. This concept can be seen at work in ant and termite colonies, beehives, market economies, and can even be modeled on one's home computer using free software such as StarLogo (Starlogo) or NetLogo (Wilensky). The idea that an ant colony is a system that organizes itself without any leader is intriguing. Each individual ant, acting with limited information, contributes to the emergence of an organized whole. “The movement from low-level rules to higher-level sophistication is what we call emergence” (Johnson 18). This new way of looking at organization as an emergent property of complex systems calls into question some fundamental assumptions about organization in general, and about learning in particular.

Not every system is a complex adaptive system; certain conditions must be met in order for a system to self-organize. First of all, the system must include a large number of agents. Constructing a simple model in StarLogo and adjusting the number of agents involved will readily demonstrate this principle. In addition, the agents must interact in a nonlinear fashion. As Kelso explains:

> If there are not enough components or they are prevented from interacting, you will not see patterns emerge or evolve. The nature of the

> interactions must be nonlinear. This constitutes a major break with Sir Isaac Newton, who said in Definitions II of the Principia: "The motion of the whole is the sum of the motion of all the parts." For us, the motion of the whole is not only greater than, but different than the sum of the motions of the parts, due to nonlinear interactions among the parts or between the parts and the environment. (Dynamic Patterns: The Self-Organization of Brain and Behavior 16)

Complex Adaptive Systems Summarized

From the discussion so far, the following characteristics of complex adaptive systems can be extracted:

1. Complex adaptive systems involve agents whose local, non-linear interactions result in self-organization by the system as a whole.
2. Complex adaptive systems exist in a mixed condition between order and chaos which enables them to achieve stability and flexibility simultaneously.
3. The agents in a complex adaptive system thrive by devising excellent solutions to difficult problems, rather than by finding best or perfect solutions.
4. Complex adaptive systems find excellent solutions by creating schemata based on regularities identified as successful, behaving in ways consistent with these schemata, and incorporating feedback to adapt the schemata for greater success.

The idea of self-organizing complex systems is a powerful one, with implications for a wide variety of hard sciences. Are there implications for education and human development as well? There are many who believe so. Lewis writes

> The turbulence in dynamic systems thinking is . . . a creative one, . . . and it promises to resolve to a coherent account of the developmental process itself. (42)

Learning and Schemata

It is no accident that the language for describing the behavior of complex adaptive systems includes the terms *learning* and *schemata*. These were consciously chosen by researchers to link familiar ideas with new descriptions of biological and evolutionary behaviors of systems, as well as the behaviors of computer programs such as Holland's ECHO that simulate those systems. Gell-Mann admitted that his use of "the term 'schema' is taken from psychology, where it refers to a pattern used by the mind to grasp an aspect of reality" (51).

Acknowledging that these terms were borrowed in this way raises the question of whether it is legitimate to assume that the terms have the same meaning in the contexts of complex adaptive systems, psychology and education. The answer is both 'yes' and 'no'. If the discussion is about conscious processes, then naturally the answer is 'no' since, to the best of our knowledge, neither slime mold nor computer systems exhibit consciousness. To avoid a lengthy philosophical argument which is not germane to the question of human learning, let us limit this discussion to systems of *living* agents and say that, for this examination at least, the computer simulations of complex adaptive systems cannot be said to learn in the same sense that the term is used in these other contexts, although they can simulate living systems that learn and, in some instances, generate original solutions.[1] Even a focus on living systems does not answer the question in its entirety, however, because there is still the matter of the slime mold, the ant colony, the immune system, and the myriad other complex adaptive systems composed of living agents but without consciousness to consider. Can a system composed of living agents but without consciousness be said to learn?

Yes, it can. To define learning as primarily a conscious human activity and judge other systems based on this view does not make good scientific sense. It makes a great deal more sense to take the longer and wider view that is supported by biology and evolutionary studies. From this perspective, a complex adaptive system *must learn in*

[1] Hall, in chapter 2 of *Beyond Culture*, would argue that confusing the simulation of a system with the system itself is a classic case of extension transference.

order to survive. To learn in this sense means to successfully adapt to change. Seen in this light, the conscious human experience of learning is only a tiny fraction of all the learning taking place in an individual human at any moment. Learning does not necessarily involve understanding or meaning. All complex adaptive systems can be said to learn in this fundamental sense of the term.

The use of the term *schema* must be taken more figuratively. Because Gell-Mann has borrowed the term from psychology, the term suggests a human experience involving meaning. The schemata of complex adaptive systems to which Gell-Mann refers are simply compressed regularities of patterns. Pattern recognition in itself does not constitute meaning in the sense of interpretation, although such recognition is a prerequisite for the construction of such meaning. Thus, to use the term "schema" [and Gell-Mann does put quotation marks around it (50)] is to set up an analogy to a conscious human experience. More recently the term schema has been adopted by computer programmers, but again, this use of the term does not involve meaning in the interpretive, psychological sense. Kelso uses the expression "informationally meaningful" (Dynamic Patterns: The Self-Organization of Brain and Behavior 70) to describe patterns involved in the coupling of biological systems, for example. Conscious awareness of this kind of coupling is entirely unnecessary, as such coupling occurs in all manner of complex systems, the majority of which lack consciousness. For the purposes of this paper, *meaning* will be used to denote a conscious experience, although not necessarily a linguistic one.

Thus, it can be said that, for this discussion, the use of the term *learning* in the definition of complex adaptive systems is a valid one, and the use of *schemata* as compressed regularities of data is valid. The attribution of conscious meaning to the schemata, however, is not necessarily a component of all complex adaptive systems.

Autopoiesis

An understanding of Maturana and Varela's concept of *autopoiesis* will help to guide the following discussion of the human individual as a complex adaptive system. According to Maturana and Varela:

> That living beings have an organization, of course, is proper not only to them but also to everything we can analyze as a system. What is distinctive about them, however, is that their organization is such that their only product is themselves. The being and doing of an autopoietic unity are inseparable, and this is their specific mode of organization. (48-49)

Luisi, in an article reviewing the history of the concept of autopoiesis and its possible future applications, points out that Varela was reluctant at first to apply these concepts to forms of life beyond the single cell (52). However, Maturana and Varela define a unity in terms of its autonomy and argue that the mechanism they call autopoiesis is the process by which an autonomous unity becomes manifest (47-48). Luisi argues that humans (and all other forms of life) qualify by Maturana and Varela's definition as autopoietic entities (52). A human is a living being and the being and doing of a human individual are inseparable, a unity.

Autopoiesis can be understood as a dynamic process through which a unity becomes distinct, and at the same time inseparable, from its environment. This is not a linear, but an integrated process. This sounds very much like the previous descriptions of complex adaptive systems in which continual mutual transformation of agents and systems (and systems within systems) results in adaptation and survival. In spite of their similarities, it is important to note the distinction between autopoietic complex adaptive systems and other complex adaptive systems: autopoiesis is particular to living entities; in fact, it is a definition of life.

As Luisi explains

> The emergence of life . . . is a very special novel emergent property: with life, an autopoietic unit acquires the singular property of becoming a biologically autonomous system, namely one that is capable of specifying its own rules of behavior. (52)

He further explains the argument posed by Varela and his colleagues that the integrated process of co-creation described by autopoiesis applies equally to life and cognition, including human cognition and consciousness (55). If this view is correct and cognition is an emergent property of autopoietic systems, and if autopoietic systems are likewise complex adaptive systems, then cognition as a complex adaptive system is a valid concept.

The autopoietic living organism endlessly creates itself. The being of a unity is inseparable from its doing, or action, and exists within the context of itself and its internal and external dynamics. This means that integral to any autopoietic entity and its environment is the history of their interactions. The importance of the dynamics of process and context will be stressed again by Kelso in his work, and is a vital theme in the study of all living complex adaptive systems.

The Human Individual as a Complex Adaptive System

In order to exhibit self-organization, a system as a whole must behave in a way that is not controlled by any particular agent of the system. It is characteristic of complex adaptive systems that the actions of agents acting locally result in system wide organization. Until recently it might have been possible to argue that an individual's genetic code controlled the ultimate organization of an individual human. Now that the human genome has been decoded, it is clear that the system is much more complex than was previously imagined (Watts 26; Johnson 84-86). As it turns out, from the very first cells on to the emergence of the individual human, individual cells determine how to differentiate into the variety ultimately necessary to create all the components of an individual by interpreting DNA in the context of information received from neighboring cells. Thus, individual cells acting locally self-organize into a human being with the genetic code as a sort of guidebook.

But once the central nervous system is well formed, does it "control" the rest of the human and all its systems, including learning? This is a controversial topic, but evidence suggests that such is not the case. Maturana and Varela assert that "the nervous system is an expression of its connectivity or structure of connections and … behavior arises because of the nervous system's *internal* relations of activity" (126). They insist that a great deal of the trouble in understanding cognition is a result of not keeping a "logical accounting in order" (136), by which they mean that it is vital in descriptions to distinguish between what is happening within a system and what an observer outside the system observes. This can become quite confusing when considering the systems within systems that constitute the human individual, and beyond the individual, the social, cultural, physical, economic and technological systems of which that individual is a part.

Although Maturana and Varela do not refer to complex adaptive systems per se, their argument follows the same general ideas. To fully understand how it is that the brain or central nervous system does not control the individual, it will help to understand the concept of *structural coupling*. As they explain:

> In describing autopoietic unity as having a particular structure, it will become clear to us that the interactions (as long as they are recurrent) between unity and environment will consist of reciprocal perturbations. In these interactions, the structure of the environment only *triggers* structural changes in the autopoietic unities (it does not specify or direct them), and vice versa for the environment. The result will be a history of mutual congruent structural changes as long as the autopoietic unity and its containing environment do not disintegrate: there will be a *structural coupling*. (75)

Thus, if one accepts Maturana and Varela's argument, the behavior of an autopoietic unity always exists within a context that consists not only of a physical environment in time, but a history of interactions which results in structural coupling. Kelso makes the additional point that, in order for behavior to be successful in terms of adaptation, the coupling must "reflect functional, not merely mechanical constraints" (Dynamic Patterns: The Self-Organization of Brain and Behavior 70).

Maturana and Varela distinguish between structure and organization in a way that correlates with descriptions of complex adaptive systems, where *organization* is the equivalent of the ongoing identity of the system and *structure* equates to the elements of the system. Seen in this light, structural coupling bears a striking resemblance to the regularities of compressed data that become, for example, DNA sequences or Gell-Mann's schemata.

Given this structural coupling which binds a system to its own history and to its environment, does the central nervous system qualify as a complex adaptive system? If it does, then by definition it must be self-organized. To avoid the trap of circular reasoning, one must look for evidence that such a view of the central nervous system is justified.

If it could be shown that the central nervous system exists in a state of relatively rigid order, then a view of it as a complex adaptive system would be out of the question. However, research suggests that such is not the case. In classic experiments as well as in experiences with victims of brain damage it has been shown repeatedly that within certain parameters, the brain can reorganize to adapt to its changed condition.[2] This plasticity of the brain argues against its having a rigid structure. The familiar illustration of the brain divided into sections, each one labeled with a particular function, turns out to be misleading, at best.

Maturana and Varela discuss neuroplasticity in terms of structural changes in the connections within the nervous system (166-167). They argue that the overall

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[2] For an excellent discussion of this, see Schwartz and Begley.

structure of connections, which they call “broad lines of connectivity” (167), are generally the same within a species, but that structural changes in the local synaptic interactions cause significant modifications in how the network functions. These changes are the result of interactions with the environment and endow the nervous system with its plasticity.

Kelso's work in the field of neurophysiology examines neuroplasticity in terms of the dynamics of neurological structures and correlated behaviors. Based on more than twenty years of research, he is convinced that the central nervous system is self-organized.

> The brain is fundamentally a pattern forming self-organized system governed by potentially discoverable, nonlinear dynamical laws. More specifically, behaviors such as perceiving, intending, acting, learning, and remembering arise as metastable spatiotemporal patterns of brain activity that are themselves produced by cooperative interactions among neural clusters. Self-organization is the key principle. (Dynamic Patterns: The Self-Organization of Brain and Behavior 257)

A self-organized complex adaptive system does not have an agent that is in control of the system. There is no central locus of control. Thus, if the central nervous system is a complex adaptive system, the next question is whether as such it can control the other systems with which it interacts and together with which the larger system, the individual human, is comprised. If an individual human is a self-organized, complex adaptive system, the answer must be no. If Maturana and Varela are right, then the interactions between systems can trigger changes, but cannot direct them.

The Brain as a Complex Adaptive System

Recent research on the brain has revealed that many of our former notions of brain organization were off the mark. The idea that there exists somewhere in the brain *representations* of objects or ideas seems highly unlikely in the light of results from researchers like Kelso, Fingelkurts and Fingelkurts, Varela, and many others. Their research suggests that the brain is a self-organized complex adaptive system and that the great plasticity and flexibility of the brain's functioning is due in large part to its characteristics of metastability and multivariability (Kello, et.al.; Fingelkurts and Fingelkurts). This suggests that it is the interconnectivity of neurons that is important. This interconnectivity supports processes that allow for rapid, flexible, efficient functioning.

At the same time, in spite of the enormous number of neurons in the brain, "full neuron-neuron interconnectedness would lead to brains the size of a bathtub" (Fingelkurts and Fingelkurts 5). The problem is solved by scaling, by increasing the number of synapses per neuron and the number of possible structures to which any particular structure may connect (Fingelkurts and Fingelkurts 5-6). These many possible combinations of brain states result in a high degree of multivariability.

In spite of this great flexibility, the performance of the system is constrained by specialization within particular cortical areas and by the functional connectivity within the system (Fingelkurts and Fingelkurts 8). These constraints result in what is termed metastability (Kello, Beltz and Holden; Fingelkurts; Varela, Lachaux and Rodriguez; J. A. Kelso; Wallenstein and J.A. Scott Kelso).

The model of brain functioning that is being constructed by these researchers proposes a view of the brain and neurological system as a hierarchical, multivariable network of neuronal assemblies, transiently linked, that interacts locally and globally within metastable constraints (Varela, Lachaux and Rodriguez 229). Essential to this view is the importance of the *process* of interactions, in contrast to other models that emphasize brain structure.

According to this view, the metastability of brain states is achieved by phase synchrony of brain signals. Before the synchronization occurs, however, there is an instability that leads to a phase transition; then the signals synchronize and metastability is achieved. Remember that the metastable state is not locked in; rather it is transient, but more stable (that is, more likely to occur), than other possible states. Kelso hypothesizes that phase transitions serve as switches between metastable brain states (Kelso, Instabilities and Phase Transitions in Human Brain and Behavior 2).

Arguing for the central nervous system as a complex system, Kelso has shown that there are coordination pattern dynamics that are intrinsically more stable than others. By intrinsic Kelso does not mean innate, but he means "capacities that exist at the time a new task is to be learned" (Kelso, Dynamic Patterns: The Self-Organization of Brain and Behavior 163).

> The initial state of the organism never corresponds to a disordered random network, but is already ordered to some degree. Thus, it is very likely that learning involves the passage from one organized state of the system to another, rather than from disorder to order. (Dynamic Patterns: The Self-Organization of Brain and Behavior 163)

Thus, if this is correct, phase transitions in the brain function slightly differently than those in non-living systems.

In one of Kelso's experiments, participants were asked to cycle the index fingers of their right and left hands in response to cues from two visual metronomes, one for each hand (Kelso, Dynamic Patterns: The Self-Organization of Brain and Behavior 164-170). Typically, in-phase cycling (cycling the fingers synchronously) and 180 degree antiphase cycling (regular alternating cycles) constitute basins of attraction for this kind of coordination. This means that these patterns tend to be intrinsically stable. Kelso's earlier studies demonstrated this by showing that when individuals were asked to produce cycles other than these, errors tended to occur in the direction of either in-phase or antiphase cycles, with in-phase cycling being the more stable of the two patterns. This is typical of what are called basins of attraction (Kauffman 78, 83, 102, 110; Kelso, Dynamic Patterns: The Self-Organization of Brain and Behavior : The Self-

Organization of Brain and Behavior 54, 56, 150, 168, 171)– that is, they tend to attract nearby behaviors in a way analogous to the flow of water in a watershed. One can imagine this like a landscape. Imagine that in the landscape there are two low areas. One of these represents in-phase cycling of the fingers, the other, antiphase cycling. In the case of rain on a landscape, the water in the areas around the low points naturally flows down toward them. In the case of cycling fingers, Kelso found that before learning new patterns, when people tried to cycle their fingers slightly out of phase in comparison with one of these two basins of attraction, they tended to slip into one of these more intrinsic patterns.

Wallenstein's group (of which Kelso was a part) conducted a similar experiment and observed that, during the syncopated phase of learning, on approaching the phase transition, both the observed behavioral pattern and the brain signals began to destabilize and fluctuate before finally settling into synchrony (633). This disequilibrium before a phase transition seems to be characteristic (Kelso, Instabilities and Phase Transitions in Human Brain and Behavior 2)—a context we will consider further later in this paper. A significant aspect of this study is that there was a correlation between observed learning behavior and the recorded brain signals, indicating that the same non-linear dynamic processes may operate at different levels of observation (634).

For Kelso's study, the attractor layout for each participant was determined before, during and after the experiment and these results were compared (Kelso, Dynamic Patterns: The Self-Organization of Brain and Behavior 170-171). The task of each participant was to learn a cycling pattern of 90 degrees—one that is not typically an intrinsically stable pattern. What were the results? Kelso and his group found that

> The entire attractor layout changes with learning, not simply the coordination pattern being learned. …That is, with learning, the relative phase of 90 degrees also becomes attractive for neighboring conditions.…Required phasings of less than 90 degrees are overshot,

> whereas those of greater than 90 degrees are undershot. (Dynamic Patterns: The Self-Organization of Brain and Behavior 171)

As a result of the creation of this new basin of attraction, the neighboring basins (for zero and 180 degrees) necessarily altered such that they became shallower.

In Kelso's study, individuals were seen to come to a learning task with intrinsic or pre-existing tendencies which could be mapped to show basins of attraction for dynamically stable coordination patterns. Through the process of learning a new pattern, the topology of the learner's landscape of changed in such a way that not only was a new basin of attraction created, but the pre-existing basins of attraction also altered—in other words, the entire system changed in response to the learned pattern.

If the Brain is Not in Control, What Is?

The basic problem with the question: If the brain is not in control, what is? is that it assumes that some discrete entity must be in control. As the discussion of complex adaptive systems demonstrates, the problem lies in this assumption. To really grasp the implications of what complex science asserts requires one to relinquish the assumption.

Part of the problem harks back to the point made earlier in reference to Maturana and Varela about logical accounting. Most discussions of learning are held from the point of view of an observer. In the case of human learning, this observer's point of view requires special consideration, which will be given in due course. For the time being however, the point must be made that from within the system, there is no need for an agent of control. The system organizes itself. In the case of an individual human, layer upon layer of systems organize themselves. Furthermore, each system is dynamic—learning, changing, adapting—continually searching for excellent solutions to problems as they are encountered. To use Maturana and Varela's expression, each human as a complex adaptive system is busy "bringing forth a world" (26).

Individual identity may be said to be composed of myriad complex adaptive systems which rely on one another for their existence and persistence. Learning is a component of all the complex adaptive systems which constitute a human individual, and the persistent identity which results from learning at all these levels is a product of more than the sum of these living systems. The author suggests that one cannot discuss human learning as separate from human identity. Kelso explains this beautifully in terms of synergetics (Kelso, Dynamic Patterns: The Self-Organization of Brain and Behavior 9)[3]. He says that in self-organizing systems there exists a kind of circular causality which is the result of the relationship between the cooperation of the individual agents in the system and the feedback the system receives from its environment. Far from being a linear cause-and-effect type of relationship, however, in complex systems there are so many interconnected variables that a simple, linear approach to understanding is woefully inadequate. Kelso further explains that in these complex systems "there is no reference state with which feedback can be compared and no place where comparison operations are performed. ...Hence,... the questions of who sets the reference value, who programs the computer, who programs the programmer, and so on do not even arise" (Kelso, Dynamic Patterns: The Self-Organization of Brain and Behavior 9).

Varela, et. al. also favor a view of neural dynamics that involves reciprocal information exchange rather than a stimulus-response model. They argue that the brain integrates both endogenous activity (such as attention, preparation, and so on) and sensory information in the phase synchrony that results in large-scale integration (230).

To view learning as a dynamic of the complex adaptive systems which comprise an individual human requires a shift of perspective. One has to relinquish the notion of the outside agent that controls the system in favor of an understanding of the immensely intricate dynamics of interrelations between and within systems from which no agent can be extricated. Every agent is necessarily a part of the system at some

[3] For more on Synergetics, see H. Haken’s *Synergetics: An Introduction*; *Advanced Synergetics*; and *Information and Self-Organization*, all published by Springer.

level. This is as true of conscious identity of oneself as it is of any other apparent observer.

The metaphor of the mind as a computer that controls the machine of the body does not hold up to scientific scrutiny. This is a crucial point when it comes to understanding the relationship of the nervous system to individual identity and a discussion of human learning. If Kelso is right, this challenges some of our assumptions about who we are as humans, how we learn, and how best to educate ourselves and our children.

Enactive Consciousness

Consciousness cannot be considered as separate from the complex systems of which it is a part, even though the conscious self believes itself to be separate and in charge. Consciousness, and more specifically the expression of consciousness as intention, is of undeniable importance in learning, however, as we shall see. But if our model holds true, the expression of intention is only one element of communication between and within the complex systems that are a human individual.

Thompson and Varela have proposed an approach to the neuroscience of consciousness called enactive cognitive science (418). This approach is grounded in nonlinear dynamical systems theory, research into brain processes involving large-scale integration mediated by synchrony, and the earlier work of Maturana and Varela. Their proposal offers an alternative to the “neural correlates of consciousness” approach that seeks to identify a representational system that under specific circumstances will result in the conscious awareness of content (Thompson and Varela 418). They argue that the representational approach is one-way, while a dynamical systems view favors consciousness as an emergent process that is the result of “reciprocal relationships between neural events and conscious activity” (Thompson and Varela 418). A conception of the “brain, body and environment [as] mutually embedded systems” results in a view of consciousness that involves “emergence as upward causation” and “global organism-environment processes, which in turn affect (via downward causation) their constituent elements" (Thompson and Varela 424). According to this view, consciousness is an integral part of a continuous stream of interactions that are co-creative in the sense of exchanging, adjusting and adapting to information.

Intention and the Attractor Layout

Next, let us consider what is meant by the term intention. There may be a tendency to revert to the idea of the brain as the controller of the system where intention is concerned. However, the view of a programmer, be it the brain or a "genetic program," is called into serious question in light of research on complex adaptive systems and studies of the genome itself. Not only is the genome far too condensed to contain a blueprint for all the behaviors of a living system, but there is evidence that it is also not fixed, but that various components are "transposable" (Kelso, Dynamic Patterns: The Self-Organization of Brain and Behavior 140). One result of the view of biological unities being driven by "programs" of one sort or another is the prevalence of a belief in goal-directedness in biology (Kelso, Dynamic Patterns: The Self-Organization of Brain and Behavior 138-141).Kelso takes a different point of view, however, and demonstrates through research findings the viability of his approach.

> Rather than playing the role of a program sending instructions, intentionality is viewed as an integral part of the overall orchestration of the organism. Formally, an intention is conceived as specific information acting on the dynamics, attracting the system toward the intended pattern. This means that intentions are an intrinsic aspect of the pattern dynamics, stabilizing or destabilizing the organization that is already there. (Kelso, Dynamic Patterns: The Self-Organization of Brain and Behavior 141)

So, what can it mean to say that intentions are intrinsic to the pattern dynamics of a system? What it means is that intentions are not outside forces acting on the nervous system, but instead are parametric influences contained within and constrained by the nervous system itself. Maturana and Varela (135-137) explain this well when they insist that we keep our logical accounting in order. They point out that what seems to observers to be an influence from outside the system, or an internalizing of such an influence, is logically the result of structural coupling. Because of a tendency to view systems as being controlled by centralized forces rather than being self-organized, the understanding of this requires a conceptual shift. Without such a shift, it is difficult to conceive of intention (which in this discussion is a function of consciousness) as arising from within the central nervous system. It is tempting to attribute intention and other aspects of consciousness to some outside force. "But as we know," Maturana and Varela point out, "to make this description would undermine our logical accounting: as though something useful to us for communication between observers were an operational element of the nervous system" (172).

An important strength of Kelso's approach is that he does keep his logical accounting in order, that is, he defines intention and its effects in terms of one and the same system. In this way he avoids some of the pitfalls of other approaches to studies of the effects of intention. There are logical inconsistencies inherent in, for example, defining intention as a qualitative psychological function, considered as a force outside the central nervous system, and then measuring the effects of intention (often defined in terms of goal-directed behavior) using an experimentally quantitative system. As Kelso also points out, such a mixed approach also avoids the question of to what extent an organism's existing organization constrains its intentions (Kelso, Dynamic Patterns: The Self-Organization of Brain and Behavior 146). But for the possible educational implications, it is vital to know how an individual's abilities are constrained and how to expand each learner's capabilities. In Kelso's experiments, intention is expressed with regard to a particular motor movement, for example, the cycling of fingers as described previously.

Part 2: The Learning Landscape

Introduction to the Learning Landscape

> There are always multiple layers in a landscape. That's why revisiting a landscape is never boring. Every time we return, we see it in a different light. We normally see an intermingling of different aspects of multiple sub-landscapes when we appreciate the beauty of the whole. (Visser)

Visser writes about the "learning landscape" as a way of visualizing the external contexts within which learning takes place. Kelso maps the interior learning landscape. The concept of the learning landscape fits nicely with the research on complexity and learning, as well as providing a visual metaphor for the next portion of this discussion.

The previous discussion of complex adaptive systems and brain functioning lends itself to a view of learning as an active, evolving process rather than as a product. In addition, it suggests that the learning process is a nonlinear one. Simple ideas of cause and effect cannot adequately describe the learning process. The ever-changing nature of the learning process makes a definition of learning in terms of products unworkable. The very best one can hope for by naming products is a snapshot of a moment, recognizing that, like all snapshots, the moment it describes is irretrievably transformed by time. Thus, the snapshot can never provide a definitive description.

Not only does this perspective require one to view learning as a process which is inextricable from the system of which it is a part, it requires a recognition of each human as a unique entity within whom there is an irreducible and irreproducible context in which learning is taking place. The context is irreproducible in any other human, as well as in that same human at a different moment in time. Learning is not the process of capturing a moment, but a process integral to creating the moment. This is an important distinction, and one which merits consideration in any discussion of the design of formal learning environments.

Biologue

The idea of continuous dialogue fits well with what has been discussed about complex adaptive systems as well as autopoietic unities. In an attempt to capture an even more dynamic notion—an image of many, many dialogues occurring simultaneously, at many levels of living interactions, a new term is proposed: *biologue*.

Biologue encompasses the concept of interactions and transformations occurring simultaneously at all levels (in this case, the term levels denoting differences of scale and organization) of complex biosystems. In fact, as a starting point, biologue may be described in precisely these terms. *Biologue is the continual interaction and transformation occurring at all levels of a complex biosystem.*

Learning itself can be seen in terms of this biologue. One possibility is to describe learning as the biologue of a self-organizing complex biosystem through which transformation the system creates itself. Seen in this way, every agent of a complex biological system is in a continual process of transformation that is essential to the existence of the system. There is a sense of unceasing activity through which a world is created, after the ideas of Maturana and Varela (26). This description also conveys the relevance of context, both physical and temporal, within which learning takes place. And finally, inherent in this perspective is the underlying notion of the unique history of the system, as the future of the system is created within the context of its physical and temporal present, the present constructed from the system's physical and temporal past.

Curiosity and Learning

While learning as a process may be fairly easy for the reader to go along with, learning as a nonlinear process may be a bit more difficult. Learning as a linear activity is deeply embedded in our language and philosophies.

For example, Shulman says "learning is basically an interplay of two challenging processes---getting knowledge that is inside to move out, and getting knowledge that is outside to move in" (?). Shulman further explains "these two processes—the inside-out and the outside-in movements of knowledge—alternate almost endlessly" (?). From the point of view of complex systems, this linear alternation grossly oversimplifies the learning process. Here the view is of knowledge as a noun, a static representation in the mind, and the process of learning is seen as an attempt to move discrete units of knowledge back and forth between the learner and…what? or whom?

To use the word *knowledge* in reference to learning is to conjure an image that belies the intricate dynamics of which current brain research suggests knowledge is comprised. Maybe it is time to reconsider our conception of that word, maybe even replace it with a new concept, the verb: *knowing*—to signify the verb *know* in the present progressive tense. It is a simple change that conveys a dramatic change of perspective.

Visser, whose work is steeped in an understanding of complex dynamics, defines human learning as "the disposition of human beings, and of the social entities to which they pertain, to engage in continuous dialogue with the human, social, biological and physical environment, so as to generate intelligent behavior to interact constructively with change" (Visser, Integrity, Completeness and Comprehensiveness of the Learning Environment: Meeting the Basic Learning Needs of All Throughout Life 453). Thus, according to Visser, learning is more a disposition of mind than an activity—more a readiness to act than a particular action. For our discussion, Visser's definition might be productively applied to the term *curiosity* .

Visser has further suggested that this disposition "is based on openness of mind and willingness to interact, i.e. on the readiness to give and in the process receive" (Visser, The Conditions of Learning in the World of the Twenty-First Century 8-9). This captures beautifully the notion of curiosity.

If one looks simply at the idea of willingness and readiness to interact, it can be said that this definition might apply to complex systems in general. In fact, this precursor to learning, this learning potential, may be said to be fundamental to complex system dynamics.

This view of curiosity, like the view of learning previously discussed, may have consciousness as a component, but consciousness is not necessarily required. It is more of a biological approach to curiosity. Webster's defines curiosity as, "a desire to learn" (Guralnik 153). The desire need not be a conscious one, but rather is an innate disposition (to use Visser's term) toward learning.

The reader might question the value in viewing curiosity and learning from this biological perspective when considering the design of formal learning environments. The value lies in approaching an educational environment with the assumption that every participant is naturally predisposed toward learning and in fact, is learning all the time. To design with this assumption in mind is to see the designer’s (and the teacher’s) role as more of a facilitator than as one who is to impart knowledge packets that must somehow be “gotten into” the learner. When we encourage an innate disposition to learn, we are activating a biological imperative.

Even if one can accept that every participant is learning, there may be a discrepancy between the learning taking place and the learning intended by the teacher, curriculum designer, parents, facilitator or society. The focus in the educational system is often on what is not being learned, rather than what is being learned. The situation is further complicated by the fact that even learners themselves often cannot identify, are often not even aware of, vast tracts of their own learning landscapes.

Then, what is the point of talking about curiosity and learning without consciousness? First of all, simply assuming that everyone is learning all the time might move the focus within the educational system from lack to abundance. A focus on the abundance of learning might generate a more encouraging environment for all concerned. Secondly, the admission that no one can possibly fathom the entire learning landscape and its continual transformation might stimulate questions about how learning is or should be assessed. Thirdly, and possibly most importantly, such an approach might encourage greater mindfulness regarding how and what manifestations of learning are valued.

Consciousness and Learning

This paper has argued for a view of learning as a process that is fundamental to living and inseparable from it. Now the focus is going to move from this general understanding toward some aspects of learning that are of particular concern to those involved in formal learning environments. The first of these topics is the role of consciousness in learning.

A theory of consciousness is well beyond the scope of this paper. It will not be necessary here to determine the origin or nature of consciousness, or to define consciousness in specific terms. A simple definition (taken from Webster's New World Dictionary) of consciousness as “awareness” will suffice (Guralnik 132-133). This conventional use of the term consciousness will be entirely adequate for the discussion to follow.

From the discussion so far it could be said that if a complex adaptive system exists, then it is engaged in biologues in which learning is taking place. Similarly, if learning is not taking place then the system ceases to exist. Therefore, it is safe to assume that in every living human, learning is continuously taking place. If an individual human is a complex adaptive system comprised of many other complex adaptive systems, it can also be said that biologues are going on simultaneously at many different scales.

For the sake of discussion, I'd like to suggest a somewhat arbitrary division of these many biologues into three categories with regard to consciousness: 1) those of which one is unaware, 2) those of which one has the potential to be aware, and 3) those of which one is aware. The first category—biologues of which one is never aware under ordinary circumstances—would include those taking place at the cellular level, for example. With the possible exception of certain laboratory situations, a human individual is entirely unaware of the firing of neurons in the central nervous system and the exchange of gases involved in respiration. If one can accept that these cellular systems are indeed complex adaptive systems, then learning at this level is certainly taking place. While such learning is of great importance to the survival of an individual, it is not generally considered a subject of consciousness. This is not to say that consciousness cannot affect these processes, only that the processes themselves, at a cellular level, are not subject to conscious awareness. For ease of discussion, this level of learning will be referred to as nonconscious learning.

Research also suggests that unconscious learning is taking place during the myriad interactions with one's social and physical environments as one goes about the business of daily living. For example, one may feel uncomfortable in meeting a particular person for the first time, and without realizing it, step back a pace or two from that person. This bias may likely be the result of unconscious learning.

Unconscious learning and responses also have great value for survival. For example, a friend once described a situation in which she was waiting at the curb for a bus. She was reading while she waited, her conscious attention focused on the book. Suddenly she realized that she had jumped back as a car had come up over the curb in the place where she had been standing a moment before. Her body responded to the threat before the danger had had a chance to register in her consciousness. She only realized what had happened after the event. LeDoux discusses the fact that reactions such as this bypass the cortex, thus they are not subject to conscious interpretation while they are occurring (163). This bypass buys the human the tiny bit of extra time that may mean the difference between life and death. Unconscious learning is a powerful force in the human experience and the implications for formal learning environments are intriguing. We will explore this idea further in the next section.

The second category—biologues of which one has the potential to be aware—might include activities of the systems mentioned above, but occurring on a larger scale. For example, breathing is an activity of the respiratory system of which one is generally unaware. However, it is easy to raise breathing to the level of awareness, and even to change breathing patterns through intention. Other types of biologues in this category might include habitual or routine interactions, skills one has learned and at which one is proficient, concepts which are well understood, and conscious beliefs. During these types of biologues, adjustments and adaptations may be taking place without one's active focus or awareness. For example, it is a common experience to have driven a route traversed many times before with no conscious recollection of the journey.

The third proposed category includes biologues of which one is aware, such as whatever thoughts are being attended to and focused interactions with elements of one's internal and/or external environment which are not routine or habitual. It will be clear to the reader that there is not specific division between categories two and three of this description, as activities in category two have the potential to move into category three, and activities in category three may pass into category two.

The main point of this discussion of learning and different degrees of consciousness is to illustrate the fact that, while schooling focuses almost entirely on conscious learning, conscious learning constitutes only a small fraction of all the learning taking place in an individual at any particular moment. At the same time, the learning going on at all levels, conscious, potentially conscious, and nonconscious, comprises the entire individual context in which new learning is taking place. This raises the question of whether one can take into account a learning landscape the totality of which is unknowable.

This paper argues that the impossibility of knowing the totality of the learning landscape is not as important as understanding that such a vast, ever-changing landscape exists. In addition, research into cognitive processes is revealing parts of the learning landscape which have previously been entirely hidden from view. Our decisions about how to design and implement structured learning environments can benefit from these new perspectives.

Furthermore, this perspective suggests questions about the strict focus on conscious learning in formal learning environments. As Dewey said, " Children doubtless go to school to learn, but it has yet to be proved that learning occurs most adequately when it is made a separate conscious business" (Dewey, Democracy and Education)

Unconscious Learning

While the main focus in structured learning environments has typically been on conscious learning, unconscious learning might also be put to good use in the classroom. In fact, ignoring the major influence of unconscious learning may have a detrimental effect on the conscious learning that is taking place.

In contrast to the three levels of awareness suggested above, researchers in cognitive psychology have developed several dual-processing theories of cognition (Kaufman445-447; Kahneman 19-30). Although they do not agree on the particulars, in general these theories posit Type 1 processes, which are fast and typically occur beyond the reach of conscious awareness, and Type 2 processes, which are slower and more deliberative, and which are the domain of the conscious mind. Type 1 processes, Kaufman writes, “are heavily influenced by context, biology, and past experience; and aid humans in mapping and assimilating newly acquired stimuli into preexisting knowledge structures” (445). These Type 1 processes are continuously working, sometimes to our benefit, and sometimes to our detriment. They are expert at finding patterns and, in the absence of multiple instances to draw conclusions from, will generalize from a single experience (Hill, Lewicki and Czyzewska 385). This explains, to a certain extent, how we can express biases that are in direct conflict with our consciously held beliefs (Hill, Lewicki and Czyzewska 386; Kahneman 79-88).

But the speed of Type 1 processes and their accurancy without the intervention of Type 2 consciousness makes it possible to learn highly complex information that might otherwise be unavailable. In many experiments, Lewicki and his colleagues have demonstrated the efficiency of nonconscious learning and the inability of the conscious mind to identify or articulate the learning that has occurred (Lewicki, Hill and Czyzewska 797-798). The conscious mind, however, benefits from the learning that has taken place at the unconscious level.

Although Lewicki's research suggests that conscious beliefs and goals do not seem to influence Type 1 processes (800-801), some researchers believe that Type 1 processes may be affected by nonconscious goals (Eitam, Hassin and Schul 261, 266). Eitam, Hassin, and Schul conducted two experiments, each designed to detect any difference in implicit learning between two groups of subjects. In one experiment, the implicit learning task was a simulation of a sugar factory. In the other experiment, the implicit learning task was a serial reaction time task involving reacting to the location of a disappearing and reappearing circle on a computer screen. The participants in each experiment were primed with a seemingly unrelated task: completing a word search puzzle. One group in each of the two experiments was given a word search puzzle that included motivational terms such as *excellence*, *aspiration*, and *win*. The second group in each experiment was given a word search puzzle with motivational neutral terms such as *carpet*, *hat*, and *topaz*. While the participants did not differ in their explicit motivation or explicit knowledge after completing the implicit learning task, there was a significant difference in performance between the two groups (Eitam, Hassin and Schul 265-266). The word search puzzles were not directly related to the implicit learning tasks, but they had a measurable effect on learning. The implications for even the most seemingly insignificant aspects of the learning environment are profound.

Disequilibrium

The reader may recall a reference earlier in this paper to the fact that complex adaptive systems continually move between order and disorder, never settling in one state or the other. This very movement, or disequilibrium, engenders the flexibility necessary for the system's ongoing participation in the dance of co-creation. Gell-Mann considers the process of thinking a complex adaptive system. To view thinking in this way, to acknowledge the continual disequilibrium and its concurrent creative potential, is to invite questions about the place of such potential in formal learning environments.

A complex adaptive system does not exist in a state of total disorder; such a system is a chaotic one. Instead, there is always a certain degree of order present—

some order, but not enough to lock the system into stasis. If the existing, dynamic order of thinking in an individual is an integral part of the context within which thinking takes place, then it stands to reason that the disequilibrium of each individual's thinking within each one's unique, dynamic learning landscape may be the most vital component to consider when designing formal learning environments. As we have seen previously, just before phase synchronization occurs in the brain, disequilibrium becomes pronounced. In the experiments we have discussed, there was a slowing of response time just before phase synchrony of the new skill took place. This might mean that a genuine change in the learning landscape of an individual may be preceded by some sort of confusion, awkwardness, or uncertainty. In learning a simple motor skill, this period is quite brief. Does this same process occur over a longer period for more complex tasks or skill acquisition? Do we allow for this in our classrooms? Is there time available for this kind of transition to take place?

Inquiry and the Search for Excellent Solutions

At this point, let us revisit a crucial feature of complex adaptive systems: the search for excellent solutions. The reader may recall that the theory maintains that complex adaptive systems engage in the search for excellent solutions to whatever problems are encountered. Without specifying what those problems might be, the implication is that they are co-transformations that require adjustment in order for the system to survive. These excellent solutions result in maximum fitness for the system. Maintaining maximum fitness allows the system to persist, and more than that, to thrive. How can a view of thinking as a complex adaptive system and the search for excellent solutions inform formal learning environments?

In complex adaptive systems, finding a single best solution is impractical, maybe even impossible, due to the constraints of time and the vastness (with respect to the searching agent) of the landscape within which the search takes place. As was previously mentioned, Holland and Kauffman have shown that, rather than search for a single best solution, the ability to adapt to an ever-transforming landscape requires finding one or more excellent solutions to the presenting problem. The assumption is that any number of excellent solutions may be discovered.

Contrary to this view of the possibility of many excellent solutions for a presenting problem, often formal learning environments are organized around the assumption that there are single best solutions to well-known problems, and that these best solutions, in most cases, have already been discovered. Building on this assumption, the role of the teacher is often seen as to provide students with this best solution information, referred to in this system as "knowledge." In turn, students are evaluated on their ability to demonstrate understanding of such knowledge in the form of "right" answers.

There are several significant consequences of this approach. One is that any answer that is not considered the right one, is considered wrong. This dichotomy contradicts what we know of the history of human thinking. Nowhere is this more evident than in the flow of scientific inquiry. If, for example, the theory of the earth as the center of the universe had been accepted as the single "right" one, then most of the ways we communicate about the cosmos via modern science would not have been developed. Piaget expressed this idea in a 1968 lecture on his theory of genetic epistemology.

> Scientific knowledge is in perpetual evolution; it finds itself changed from one day to the next. As a result, we cannot say that on the one hand there is the history of knowledge, and on the other its current state today, as if its current state were somehow definitive or even stable. The current state of knowledge is a

> moment in history, changing just as rapidly as the state of knowledge in the past has ever changed and, in many instances, more rapidly. Scientific thought, then, is not momentary; it is not a static instance; it is a process. More specifically, it is a process of continual construction and reorganisation.

Finding the single right answer spells the end of thinking. Since an important component (some might argue the most important component) of schooling is to engage students' thinking, it can be seen that the single right answer approach contradicts this aim. One might argue that the idea of the earth as the center of the universe was always wrong, but that people just didn't realize it until the real right answer—the earth as simply one of several planets that orbit the sun—was discovered. I would counter by saying that in itself is evidence enough for us to question the assumptions we believe to be true.

Dewey considered the problem of insisting that students get the right answer, as well. He wrote that it was "impossible…to exaggerate the hold that this attitude has upon teaching in the schools" (Dewey, Intelligence in the Modern World 689). He said that one reason for the prevalence of the right answer approach was a misunderstanding of the alternatives, with many educators believing that without the resolution provided by such answers, students minds would be left in confusion. In response to this attitude, Dewey commented, "The real alternative to settling questions is not mental confusion, but the development of a spirit of curiosity that will keep the student in an attitude of inquiry and of search for new light" (Dewey, Intelligence in the Modern World 689).

Another drawback of the single best answer approach is that it defines the student's task as to find the answer rather than to think about the problem. The focus is shifted from the process to the goal. This subtle shift is critical in instilling a pattern of thinking I have often encountered in the secondary classroom. Since the goal is seen by students as to get the right answer rather than to think about a particular problem or situation, students tend to develop the skills they need in order to accomplish the goal. If the student has been able to figure out how the teacher thinks, getting the prescribed answer (in the prescribed way) may be easy. If not, and if that is the only way that is deemed acceptable, a student may rely on other skills to find the answer. These might involve copying the answer from the student who has figured it out, copying from the Internet, or stealing the answer key. The problem then expands from the original, seemingly simple question of right and wrong answers to the more complex question of ethically right and wrong actions. On several occasions I have been told in sincerity by students that these alternative methods of achieving the goal of the right answer were not wrong if one didn't get caught at them. Apparently to these students, since the only thing that really “counts” is the right answer and the final grade, the means of achieving it is of secondary importance.[4]

So, what kind of approach in formal learning environments can support the search for excellent solutions? One possibility is that of guided inquiry. This is inquiry motivated by student-generated questions. The quality of questions generated by students varies widely, however, and it is one role of the teacher to guide students in formulating good questions. This is not to suggest that the teacher must have one right question in mind, which the students are required to guess. Rather, the teacher can encourage each student to evaluate his own questions until he can discern which of them are worth pursuing. There can be no right or wrong questions, only some that might lead to productive exploration and others that are unlikely to produce valuable experiences. There is an element of subjectivity involved, and the student's own intuition must be respected. By providing guidance within the context of the student's own interest and intuition, a teacher may encourage the confidence required to maintain rigorous inquiry.

[4] See Brooks and Brooks, page 67.

What constitutes a good question is not, as one might suppose, the likelihood that pursuit of the answers will produce a correct result. On the contrary, a good question is one that stimulates productive inquiry regardless of the end result.

> "Good questions" are ... good because they engage our minds in complex processes of analysis - uncovering unstated assumptions, and searching for evidence that will lead us to logical, reasonable conclusions. (Barell 80)

Those reasonable conclusions may or may not produce a correct answer. The process of reasoning is what is most important. The purpose of formulating good questions, then, is to encourage thinking. Dewey points out that "the first stage of contact with any new material, at whatever age of maturity, must inevitably be of the trial and error sort" (Dewey, Democracy and Education). Of necessity, there is a certain amount of trial and error involved in thinking, particularly when a topic is first encountered. A recognition and accommodation of this trial and error phase of inquiry can aid in the search for excellent solutions.

Generating ideas and pursuing possible avenues of thought is time-consuming. The thinker makes false starts and wrong turns, encounters blind alleys, collapses in a heap, reconsiders, and starts again. It is all part of the search. This may seem to be a waste of time, particularly when the teacher or textbook is perfectly capable of providing a "right" answer without all the bother. However, there may be no quicker way to stymie student interest and motivation than to present material as if all the answers have already been found and the student's job is simply to memorize them. It is crucial to allow students to take the time they need to make their own discoveries. Providing the opportunity for students to discover answers for themselves also encourages them to develop invaluable thinking skills, which can make learning more interesting and effective.

Dewey, whose writing of 1916 seems almost to predict the current study of complex adaptive systems and Maturana and Varela's work in biology, advocates designing learning environments that encourage inquiry and exploration. This quote reminds one of Maturana and Varela's concept of structural coupling:

> A response is not just a re-action, a protest, as it were, against being disturbed; it is, as the word indicates, an answer. It meets the stimulus, and corresponds with it. There is an adaptation of the stimulus and response to each other. A light is the stimulus to the eye to see something, and the business of the eye is to see. If the eyes are open and there is light, seeing occurs; the stimulus is but a condition of the fulfillment of the proper function of the organ, not an outside interruption. To some extent, then, all direction or control is a guiding of activity to its own end; it is an assistance in doing fully what some organ is already tending to do. (Dewey, Democracy and Education)

The concept of structural coupling can inform the way teachers help guide thinkers in formal learning environments. With a view of thinking as a complex adaptive system within which curiosity, the potential for learning, is innate and learning itself proceeds continuously, the teacher can be seen as one who facilitates these processes rather than one who instigates them. Moreover, everyone involved in the formal learning environment can be seen as a co-creator in transforming individual learning landscapes.

Correct and True

Thinking about a problem is necessarily personal as it occurs in the unique personal contexts mentioned in previous sections. The thinker is engaged in a learning activity, discovering and making connections. Finding an answer, on the other hand, is seen as a process in which the individual learner has no voice. The answer has already been discovered, the single best solution has already been worked out by someone else, and the student's job is merely to memorize, reiterate, or duplicate it. This approach distances the student from the problem and lessens the possibility that the process of finding a solution will be incorporated into the student's conscious learning landscape, or that she will be able to find the prescribed solution at all. As Paley observed of her work with 3-year-olds, "Tempting as it may be to set the record straight [regarding whether or not a particular student's mother has a birthday, for example], I have discovered that I can't seem to teach the children that which they don't already know" (Duckworth 158). What is true for a learner is that which has been incorporated into the learner's individual learning landscape. Thus, what is deemed correct may simply not be true in a particular learner's case.

Duckworth offers plenty of examples that illustrate this point. Her work, strongly grounded in that of Piaget, has led her to an approach to teaching that encourages students, no matter their ages, to become aware of their own ways of thinking and transforming conscious experience. This approach is student-centered and requires that the teacher stay attentive and actively engaged in the students' own reasoning processes. One important way the teacher stays engaged is by asking open-ended questions that offer opportunities for the students to examine and test their own ideas. Here Duckworth describes the process.

> Instead of explaining to the students, then, I ask them to explain what they think and why. I find the following results. First, in trying to make their thoughts clear for other people, students achieve greater clarity for themselves….Second, the students themselves determine what it is they want to understand….Third, people come to depend on themselves: They are the judges of what they know and believe. They know why they believe it, what questions they still have about it, their degree of uncertainty about it, what they want to know about it next, how it relates to what other people think. Any other "explanation" they encounter must establish its place within what they know. Fourth, students recognize the powerful experience of having their ideas taken

> seriously, rather than simply screened for correspondence to what the teacher wanted [sic]. Fifth, students learn an enormous amount from each other….Finally, learners come to recognize knowledge as a human construction, since they have constructed their own knowledge and they know that they have. (158-159)

The gifts of such an approach are apparent. Not only do Duckworth's students take an active role in their learning, driven by innate curiosity and guided by their own reasoning processes, but they also develop metacognitive skills. This metacognition can serve them in learning situations throughout their lives, as it is the key to learning how to learn.

Practice! Practice! Practice!

There is an old joke in the U.S. that goes like this:

> A tourist is walking down the street in New York and he stops someone to ask for directions. *“How do you get to Carnegie Hall?”* he asks. The respondent answers, *“Practice! Practice! Practice!”*

Carnegie Hall is a concert performance venue. For many artists, the chance to perform there represents the epitome of a career.

In addition the opportunity to explore for excellent solutions, the research suggests that learning at the conscious human level also requires time for practice and mastery. In Kelso’s simple experiment with the cycling fingers, participants were not immediately able to perform the activity out of phase with the nearby basins of attraction. The change to the learning landscape required work and practice.

To many readers, this point may seem obvious. But the emphasis on testing and the requirements that more and more content be covered per term have resulted in less time for exploration and mastery in the typical classroom.

In addition to more time for practice, we need to provide a variety of options for practicing, including verbal, kinesthetic, and visual.

In Defense of Reinventing the Wheel

A common expression in English cautions one against "reinventing the wheel"—the implication being that rediscovering what has already been discovered by someone else is a waste of time. This may be one of the underlying beliefs of our current educational system. Seen from that perspective, the logic of encouraging students to achieve right answers makes sense. Such an approach theoretically avoids wasting time by giving students the knowledge of what has gone before. Presented in this way, knowledge is static, unchanging, correct.

However, if a human being is a complex adaptive system, and if learning is a dynamic of that system through which transformation occurs as a result of the experience of co-creating the world, then such an approach is, in fact, an utter waste of time. Seen from this point of view, the wheel must be invented again and again, by each one in his or her own way.

In this contradiction is the essence of a major struggle in educational practice. In an effort not to waste time and to demonstrate the "results" on which funding and public support depend, formal educational practice is designed to fill students' minds with data that can be measured and graded. This practice depersonalizes the educational experience, creates an environment in which students compete with one another for their places on the bell curve (Hartwell) and values getting "the right answer" over personal vision and the co-creation of meaning. Simultaneously, educators, parents and students themselves bemoan the lack of student engagement, low levels of critical thinking ability and high disillusionment with a system in which students are often seen as unable or unwilling to learn. We as a learning society can't have it both ways. We can choose either to set up flexible learning environments in which learners can take the time they need to create personal understanding or we can continue with the present system, thereby giving up the benefits of such an approach.

> Why is it, in spite of the fact that teaching by pouring in, learning by a passive absorption, are universally condemned, that they are

> still so entrenched in practice? That education is not an affair of "telling" and being told, but an active and constructive process, is a principle almost as generally violated in practice as conceded in theory. Is not this deplorable situation due to the fact that the doctrine is itself merely told? It is preached; it is lectured; it is written about. But its enactment into practice requires that the school environment be equipped with agencies for doing, with tools and physical materials, to an extent rarely attained. It requires that methods of instruction and administration be modified to allow and to secure direct and continuous occupations with things. Not that the use of language as an educational resource should lessen; but that its use should be more vital and fruitful by having its normal connection with shared activities. (Dewey, Democracy and Education)

Dewey's words ring as true today as they must have in 1916.

Another possibility is that everyone involved can actively engage in a search for excellent solutions to the dilemma of our present system. It seems likely that we are capable of generating many excellent solutions, and their efficacy in the changing learning landscape will surely change as well. Complex adaptive systems exist in an ever-changing state somewhere between order and chaos. They simply cannot exist in a rigidly ordered state, nor can they self-organize in a state of chaotic disorder. Maybe one secret of successful educational reform lies in the understanding and application of this idea. Instead of searching for the single best approach to education, our system might benefit from an acceptance, even a celebration of its transformational nature, that is, the necessity of its continual transformation and its ability to simultaneously transform its participants.

Summary and Questions

The study of complex adaptive systems suggests that beauty and organization may, under certain conditions, arise spontaneously as a result of the actions of many agents acting locally and without a specific leader. Such study generates an image of systems at many scales which are involved in continuous transformation, dynamic and vibrant. In such systems, the synergistic whole is, indeed, greater than the sum of its parts and inseparable from them. Viewed through a biological lens and brought into focus by the work of Maturana and Varela, this continuous transformation within and among nested and aggregate complex adaptive systems may be conceived of as the process of co-creating the world; each agent is a co-producer of a future fashioned out of myriad possibilities. In complex adaptive systems, flexibility is the key to success.

When these ideas are applied to thinking, many opportunities arise for reflection about how learning systems can be designed to best support human learning. The search for excellent solutions to the challenges of our current formal educational system might begin with questions as a point of departure. These might stimulate discussion, but might also encourage experimentation, which could generate more questions, and so on.

The point is not to find an answer, or even several answers. The underlying reality of complex adaptive systems is that they are always in a state of transformation. As such, successful solutions must themselves be flexible and subject to transformation. The challenge of such an adventure beckons those who dream of a world in which the joy of learning is the focus of formal learning environments—not entertainment, but the sweaty, difficult, exasperating, exhilarating process of bringing forth a world.

Here are some questions the reader might wish to consider. It is hoped the reader will have many more.

The Type 1 processes are unconscious, fast and efficient, capable of analyzing patterns too complex for the conscious mind to grasp, and continuously active. These *processes are not available to the conscious mind, but they inform conscious learning. Is there a way to construct formal learning environments that support unconscious learning? Are there elements in our current designs that do so? If so, what kinds of unconscious learning are being supported? Is their effect positive?*

What are the main purposes of formal education? What kinds of educational culture best support those aims?

Can the emerging understanding of complex adaptive systems and brain function productively inform formal educational design and practice? If so, how? If not, why not?

Works Cited

Barabási, Albert-László. Linked. Cambridge: Perseus, 2002.

Barell, John. Developing More Curious Minds. Alexandria: ASCD, 2003.

Brooks, Jacqueline G. and Martin G. Brooks. The Case for Constructivist Classrooms. Alexandria: ASCD, 1993.

"Complex." Webster's New World Dictionary of the English Language. New York: Warner, 1979.

"Consciousness." Webster's New World Dictionary of the English Language. New York: Warner, 1979.

"Curiosity." Webster's New World Dictionary of the English Language. New York: Warner, 1979.

Dewey, John. "Democracy and Education." 1919. http://www.ilt.columbia.edu/publications/dewey.html.

—. Intelligence in the Modern World. New York: Random House, 1939.

Duckworth, Eleanor. The Having of Wonderful Ideas. 2nd Edition. New York: Teachers College Press, 1996.

Eitam, Baruch, Ran R. Hassin and Yaacov Schul. "Nonconscious Goal Pursuit in Novel Environments: The Case of Implicit Learning." Psychological Science 19.3 (2008): 261-267.

Fingelkurts, Andrew A. and Alexander A. Fingelkurts. "Making Complexity Simpler: Multivariability and Metastability in the Brain." (n.d.).

Gell-Mann, Murray "Regularities and Randomness: Evolving Schematat in Science and The Arts." Art and Complexity. Ed. J. Casti & A. Karlqvist. New York: Elsevier, 2003. 47-58.

Gleick, James. Chaos. New York: Penguin, 1987.

Hall, Edward T. Beyond Culture. New York: Doubleday, 1976.

Hartwell, Ash. "The End of Planning: Notes on Public Policy and Educational Plans." Vimukt Shiksha Special Issue (2001).

Hill, Thomas, et al. "Self-Perpetuating Development of Encoding Biases in Person Perception." Journal of Personality and Social Psychology 57.3 (1989): 373-387.

Holland, John H. Hidden Order: How Adaptation Builds Complexity. Cambridge, MA: Perseus, 1995.

Johnson, Steven. Emergence: The Connected Lives of Ants, Brains, Cities, and Software. New York: Scribner, 2001.

Kahneman, Daniel. Thinking, Fast and Slow. New York: Farrar, Straus and Giroux, 2011.

Kauffman, Steven. At Home in the Universe. New York: Oxford, 1995.

Kello, Christopher T., et al. "The Emergent Coordination of Cognitive Function." Journal of Experimental Psychology: General 136.4 (2007): 551-568.

Kelso, J. A. Scott. Dynamic Patterns: The Self-Organization of Brain and Behavior. Cambridge, MA: MIT Press, 1995.

—. "Instabilities and Phase Transitions in Human Brain and Behavior." 11 March 2010. 28 September 2012 <www.frontiersin.org>.

LeDoux, Joseph. The Emotional Brain. London: Weidenfeld & Nicolson, 1998.

Lewicki, Pawel, Thomas Hill and Maria Czyzewska. "Nonconscious Acquisition of Information." American Psychologist 47.6 (1992): 796-801.

Lewis, Marc D. "The Promise of Dynamic Systems Approaches for an Integrated Account of Human Development." Child Development 71.1 (2000): 36-43.

Luisi, Pier Luigi. "Autopoiesis: A Review and Reappraisal." Naturwissenschaften 90 (2003): 49-59.

Maturana, Humberto R. and Francisco J. Varela. The Tree of Knowledge: The Biological Roots of Human Understanding. Trans. Robert Paolucci. Revised Edition. Boston: Shambala, 1998.

Piaget, Jean. Genetic Epistemology. Trans. E. Duckworth. New York: Columbia University Press, 1968.

Schulman, Lee S. "Taking Learning Seriously." Change 31.4 (1999): 10-17.

Schwartz, Jeffrey M. and Sharon Begley. The Mind and the Brain. New York: HarperCollins, 2002.

"Starlogo." Cambridge: Media Laboratory, MIT.

Strogatz, Steven. "Exploring Complex Networks." Nature (2001): 268-276.

—. Sync: The Emerging Science of Spontaneous Order. New York: Hyperion, 2003.

Thompson, Evan and Francisco J. Varela. "Radical Embodiment: Neural Dynamics and Consciousness." TRENDS in Cognitive Science 5.10 (2001): 418-425.

Varela, Francisco, et al. "The Brainweb: Phase Synchronizationa and Large-Scale Integration." Neuroscience (2001): 229-239.

Visser, Jan. "Integrity, Completeness and Comprehensiveness of the Learning Environment: Meeting the Basic Learning Needs of All Throughout Life." International Handbook of Lifelong Learning. Ed. D. N. Aspin, et al. Dordrecht: Kluwer, 2001. 447-472.

—. "Landscaping the Learning Environment to Create a Home for the Complex Mind." April 2001. Learning Development Institute. <www.learndev.org/dl/KinseyLecture2001-rev2.pdf>.

—. "The Conditions of Learning in the World of the Twenty-First Century." June 2--1. Learning Development Institute. <www.learndev.org/dl/Versaille2001-Paper.pdf>.

Waldrop, M. Mitchell. Complexity: The Emerging Science at the Edge of Order and Chaos. New York: Simon & Schuster, 1992.

Wallenstein, Gene V. and Steven L. Bressler J.A. Scott Kelso. "Phase Transitions in Spatiotemporal Patterns of Brain Activity and Behavior." Physica D 84 (1995): 626-634.

Watts, Duncan J. Six Degrees: The Science of a Connected Age. New York: W. W. Norton, 2003.

Wilensky, Uri. "Netlogo." Evanston: Center for Connected Learning and Computer-Based Modeling, Northwestern University.