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ABSTRACT

Chaos theory, dissipative structures analysis, and complexity theory have all been used in various branches of the sciences to examine patterns of change in complex systems. This paper considers how educational theory and research can benefit from changes in scientific fields as diverse as quantum mechanics, fluid dynamics, geology, and economics and adapt to meet the needs of students and society in the changing world of the coming century. Special characteristics of learning organizations are presented that relate open systems and shifting world views to complexity theory. The cornerstones of learning organizations include systems thinking, personal mastery, mental models, the building of shared vision, and team learning. Suggestions for transforming schools are offered to counter the traditional approaches to understanding the nature of learning and organizational change. These traditional approaches often lack vision and are unable to cope with change. A systems approach considers the transformation of schooling within the dynamic environment that relates schools with other social and political institutions. Contains 16 references. (Author/LMI)

Dissipative Structures and Educational Contexts: Transforming Schooling for the 21st Century

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Abstract

Chaos theory, dissipative structures analysis, and complexity theory have all been used in various branches of the sciences to examine patterns of change in complex systems. This paper considers how educational theory and research can benefit from changes in scientific fields as diverse as quantum mechanics, fluid dynamics, geology and economics and adapt to meet the needs of students and society in the changing world of the coming century. Special characteristics of learning organizations are presented relating open systems and shifting world views to complexity theory. Suggestions for transforming schools are not only offered but advocated given the current stagnation, lack of vision, and inability to cope with change inherent in traditional approaches to understanding the nature of learning and organizational change.

Dissipative Structures and Educational Contexts:
Rethinking Research Paradigms to Understand Teacher Change

Background

Positivism Verses New Science

Beginning with the age of enlightenment and the awareness of mathematical principles describing planetary movements, positivism became the guiding world view from which scientific, economic, and social theories evolved. The positivist approach to knowing contributed to scientific discoveries of regularities in the universe, industrialization, and capitalism and socialism (Salthe, 1991). The classical scientific and industrial world view is described by the mechanical metaphor of a clockwork universe. Predominated by Newtonian physics and Humean causation, the clockwork paradigm for science postulates we can predict the inner workings of the universe from an objective vantage point. Therefore, nature can be understood, managed, and used through empirical investigations, predictions and manipulations.

In the early 20th century, accelerated by the invention of the digital computer, discovery of dissipative structures and the development of complexity theory, the foundations of the positivist world view, were shaken. Most of reality is not deterministic with predictable linear causes to explain and control relationships (Lewin, 1992). The mechanical world of classical physics is now seen differently as one level of an evolutionary universe characterized by nonlinear and nonequilibrium physics (Chen, 1991). Sensitivity to initial conditions, nonlinear relationships, and positive feedback loops in complex systems bring into question previous assumptions that complexity arises from complex relationships and simplicity results from simple causes (Gleick, 1987). The paradox of chaotic systems is that, through the process of dissipation, disorder evolves into higher order, that is, "dissipative activity ... play(s) a constructive role in the creation of new structures" (Wheatley, 1993, 19). Deterministic chaos and the new science (discovered in scientific disciplines and social structures including physics, chemistry, biology, geology, economics, population dynamics, and medicine) has challenged fundamental beliefs about how and what we can know and control.

Ways of Knowing

Personal epistemology and socially negotiated norms for inquiry determine one's world view and approach to knowing. Habermas (1971) describes three fundamental human interests (technical, practical, and emancipatory) which intercede human experience and guide action. These interests, related to our belief structures, are the lens through which reality is filtered and explored.

The technical orientation to knowing is consistent with logical positivism implicit in the Newtonian world view (Wolf, 1981). Subject-object dualism elevates the role of the inquirer to that of objective, unbiased observer. The technical approach to knowing fragments inquiry by piecing together information in the same way a mechanic might study each part of an engine to determine why it doesn't work. Control is central to the technical interest; in research we talk about isolating variables or controlling for error. The goal of the positivist approach to knowing is to define causes so future prediction is possible.

The practical interest includes an element of ethics or value; questions of what should be studied or known guide inquiry. Additionally, while the technical interest focuses on the bottom line or end result, the practical interest is concerned with process. The skill of the scientist, from the technical perspective is related to how well the rules of inquiry are followed. The art of scientific inquiry from the practical perspective, however, involves insight and initiative. The difference between the practical and technical interests can be explored through analogy. Following a recipe to bake a cake (a skill) is not the same as the art of creating a cake. Contrary to the technical interest, the practical interest is not concerned with following the recipe to accumulate facts but is concerned with the beauty or art of inquiry. Similarly, while the technical interest studies fragmented aspects of reality, the practical interest adopts a more holistic perspective. The practical interest concentrates on clarification or understanding rather than verification or proof. "The practical interest is a fundamental interest in understanding the environment through interaction based upon a consensual interpretation of meaning (Grundy, 1987, 14).

The emancipatory interest, according to Habermas, is consistent with the practical interest but assumes an entirely different approach to knowing. While the practical interest is focused on understanding, the rules of inquiry are socially negotiated and accepted. The emancipatory interest critically examines rules for inquiry and challenges status quo. Equity and responsibility are important considerations as social institutions are challenged. While the practical interest is primarily focused on understanding the accumulation of knowledge of our society, the emancipatory perspective challenges the assumptions and implications of that wisdom.

Guiding Questions

Chaos theory, dissipative structures analysis, and complexity theory have all been used in various branches of the sciences to examine patterns of change in complex systems. These approaches to scientific investigation have completely reconstituted our place in the universe. This shift in conceptualization of our relationship with nature challenges the controlling approach of logical positivism and signifies an epistemological shift in our world perspective. New Science provides the metaphors and methods to challenge traditional research paradigms and indicates an emancipatory approach to inquiry.

Can educational theory and research benefit from applying approaches to inquiry and ideas about nature occurring in scientific fields as diverse as quantum mechanics, fluid dynamics, geology and economics? What do the developing theories of Chaos and Complexity have to offer educational researchers in our attempts to understand learning and the complexity of schooling? How can scientific notions of adaptation be applied to business notions of learning organizations to inform educational reformers concerned with transforming schools to meet the needs of our children in the coming century?

These questions will be addressed by outlining the emerging fields of Chaos and Complexity. The creation of theoretical models by business for nurturing "learning organizations" utilizing discoveries in New Science pertaining to properties of complex adaptive systems will be examined and the possibility of employing those models to transform schools into learning communities will be explored. Finally, an emancipatory approach to understanding the complexity of schools will be advocated utilizing the paradigms and techniques adopted by New Science.

Chaos, Complexity and Adaptation

Scientific 'deterministic chaos' has a special meaning contrary to our common notions about chaos. While 'chaos' used in everyday language tends to elicit ideas of things gone awry, from the perspective of New Science, chaos describes patterns of behavior or relationships in complex, open systems. More precisely, chaos can be characterized as the study of "orderly disorder created by simple processes" (Gleick, 1985, 266). Chaos is different from instability or disorder, however, at least in this scientific sense. The unpredictability of weather discovered by Lorenz is constrained by a 'strange attractor' which organizes the system within natural boundaries. The weather, therefore, is an example of a chaotic system, never repeating, always changing, which is ordered and predictable within bounds.

Associated with the paradigm shift inherent in this approach to understanding nature, chaos scientists have developed new ways of investigating nature including utilizing computer modeling and mathematics as an experimental science. Graphic images on high speed computers used to model complex relationships have led to new theories about the stock market, brain physiology, and the weather, to name a few. Fractal imaging has given us not only a new perspective on the beauty of emerging patterns in nature but has provided a new way of structuring thought about dimensionality as fractional dimensions are used to classify the complexity of relationships in fractal patterns.

"[C]haos theory has shaken science to its foundations with the realization that very simple dynamical rules can give rise to extraordinarily intricate behavior. ... And yet chaos by itself doesn't explain the structure, the coherence, the self-organizing cohesiveness of complex systems" (Waldrop, 1993, 12). Complexity theory emerged from the study of chaotic systems to describe structure and organization of complex systems. Although there is no agreed-upon definition of complexity, "Christopher Langton, a computer scientist at Los Alamos National Laboratory, has introduced an analogy that helps one think about the change between order and disorder in different ensembles of networks. He has related network behavior to phases of matter: ordered networks are solid, chaotic networks are gaseous and networks in an intermediate state are liquid. ... Interesting dynamic behaviors emerge at the edge of chaos" (Kauffman, 1991, 82). Complexity has been labeled as the balance between order and chaos and complex systems characterized as being 'on the edge of chaos.' "The edge of chaos is the constantly shifting battle zone between stagnation and anarchy, the one place where a complex system can be spontaneous, adaptive, and alive" (Waldrop, 1993, 12).

Independently discovered regularities in a variety of fields prompted the development of the Sante Fe Institute to facilitate discussion and promote the advancement of the emerging field of complexity. Rejecting positivist reductionism, complexity theorists associated with the Sante Fe Institute advocate an interdisciplinary approach and are concerned with system behavior and patterns of relationships as systems evolve. For example, Stuart Kauffman first examined the delicate balance between order and chaos by exploring biological evolution using computer modeling (Kauffman, 1991). The order in our own biological system can be seen as more than the chance occurrence of evolution but as the result of our own ability to adapt and self-organize at the microbiological level. In addition to self-organization and adaptability, other characteristics of complex systems include sensitivity to initial conditions and self-similarity. These characteristics will be described below.

Sensitivity to Initial Conditions

Computer modeling of weather by Lorenz in the early 1960's provides an example of sensitivity in complex systems to changes in initial conditions. Lorenz was simulating complex weather behavior on an analog computer using a simple system of three nonlinear differential equations. He decided to take a closer look at behavior in his system within a particular time-frame, so he re-entered the values of the equations at the beginning of the time-interval of interest and went for a cup of coffee. An hour later, he returned and saw a very different pattern from the previous run of the data. The small changes in initial values significant to the fourth decimal place had caused major deviations from the original behavior of the system. This sensitivity to initial conditions is called 'the butterfly effect' to signify the unpredictability of the effects of a butterfly flapping its wings in Hong Kong on the weather in New York a week later. The significance of this discovery, for Lorenz, was to prove that long-range weather forecasting is impossible.

Population dynamicists have studied the sensitivity of biological systems to initial conditions using computer modeling and logistic maps. While certain initial populations maintain system stability, small changes in initial population parameters can result in unpredictable and surprisingly complex behavior. At certain critical values, population stability alternates between two values. Vacillating between two stable population attractors is known as period doubling. As the system is pushed further into disequilibrium, population dynamics jump among 4, 8, or 16 cycle states, then return to 3, 5, or 7 cycle states, and finally collapse into chaos with no repeating pattern. The mathematician James Yorke proved that if any system displays cycle three behavior, it will also display behavior of every other cycle and eventually collapse into chaos. These results suggest even chaos has an order and a predictability despite the inherent indeterminacy. "[S]imple deterministic models could produce what looked like random behavior. The behavior actually had an exquisite fine structure, yet any piece of it seemed indistinguishable from noise" (Gleick, 1987, 79). Simple systems can produce extremely complex patterns of behavior.

Sensitivity to initial conditions is related to the connectedness of a system. 'Tiny perturbations won't always remain tiny. Under the right circumstances, the slightest uncertainty can grow until the system's future becomes utterly unpredictable - or, in a word, chaotic" (Waldrop, 1987, 66). The path of flight of a released balloon is chaotic, for example. The multiplicity of relationships as the balloon takes flight makes prediction virtually impossible. Nonlinearity is the mathematical interpretation of sensitivity of systems to initial conditions. Mathematical modeling of complex behavior of systems suggests nonlinearity is synergistic, i.e. that the whole of the system is greater than the sum of its parts. Even simple systems like a dripping water faucet display nonlinearity leading to chaos. Nonlinearity destroys the Newtonian expectation for predictability. A second feature of complex systems, self-organization, further challenges the possibility of control and prediction in dynamic systems.

Self-organization

An open system is characterized by an exchange of energy and information to the system. The process of applying heat to a pot of soup can illustrate the complex dynamics of self-organization first described by Prigogine (see Waldrop, 1993) characteristic of open systems. Without adding energy to the system, that is, before the heat is turned on, the soup, at room temperature, remains at equilibrium. When the heat is turned on, the system is no longer at equilibrium as heat energy becomes dispersed throughout the soup. As more heat is applied, the soup becomes unstable as molecules appear in random motion. Eventually, however, the molecules organize themselves into convection cells. The soup passes from equilibrium through disequilibrium to reach a higher level of order. This same process of self-organization was discussed by Kauffman to describe how evolution to more complex biological states is possible.

Related to self-organization are positive feedback loops. The economist Brian Arthur captures the essence of positive feedback in his theory of increasing returns. While negative feedback stabilizes a system, positive feedback amplifies the effects of small changes to the system. "The history of the videocassette recorder furnishes a simple example of positive feedback. The VCR market started out with two competing formats selling at about the same price: VHS and Beta. ... Such a market is initially unstable. ... Increasing returns on early gains eventually tilted the competition toward VHS" (Arthur, 1990, 92) Especially sensitive to the theory of increasing returns and positive feedback are what Arthur calls 'knowledge-based' economies such as high-technology and pharmaceutical. Although positive feedback transforms a system through the process of self-organization, Kauffman and Arthur both are quick to point out the 'best' possible state is not always reached through the reorganization efforts of the system. Ample examples of mal-adaptive changes in biological systems and the economy suggest there is an unpredictability and indeterminacy associated with the evolution of complex systems through the process of self-organization.

Self-similarity

Self-similarity describes repeating patterns across scales. So, for example, rather than examining yearly fluctuations of stock market trading, chaos theory considers similarity of scale on daily, monthly, and yearly patterns of change. Fractals, generated on home computers from simple recursive code, are the most popular and widely recognized aspect of chaos. Fractals reveal an underlying structure of repeating self-similar patterns across scales.

Self-similarity across scales has been noted in clouds, mountain ranges and coastlines as well as many biological features of the human body including brain waves, heartbeats, and the structure of the lungs. The discovery of fractal relationships in a wide variety of organic and naturally occurring phenomena suggests an underlying simplicity to the overwhelming complexity inherent in fractals. "As fractals, branching structures can be described with transparent simplicity, with just a few bits of information" (Gleick, 1987, 110). The efficiency of generating complexity from simple relationships may be a key to our own evolutionary history. The DNA containing instructions for producing the different types of cells in our body may rely on fractal structuring of complex networks from a limited amount of information. This same economy of information and resources has already been discovered in the biological systems construction. "In terms of the body's resources, blood is expensive and space is at a premium. The fractal structure nature has devised works so efficiently that, in most tissue, no cell is ever more than three or four cells away from a blood vessel. Yet the vessels and blood take up little space, no more than about five percent of the body" (Gleick, 1987, 108). The potential of fractal disks to efficiently store and retrieve information is being explored, modeled after research in brain physiology that suggests neural connections may be fractal.

Self-organization, sensitivity to initial conditions and self-similarity are the cornerstones of complex adaptive systems. Providing a means for generating complexity from simple relationships, sensitivity to environmental conditions, and the ability to reorganize and adapt offer complex systems ways of adjusting to and reacting with a changing world. New Science is interested in understanding relationships in complex adaptive systems as they evolve. One application of New Science to human organizations has been in the area of business dynamics. Learning organizations in the business environment will be described below. Transforming schools into learning organizations then will be addressed in the final section of the paper.

Learning Organizations

Learning organizations have been designed in business to develop and maintain complex networks, providing systems with the potential to adapt to environmental changes. Consistent with the New Science perspective, learning organizations recognize the primacy of information and positive feedback to maintain system viability and promote system growth (see Wheatley, 1994). According to Peter Senge (1990), the cornerstones of learning organizations are: (a) systems thinking, (b) personal mastery, (c) mental models, (d) building shared vision, and (e) team learning. These cornerstones will be discussed related to chaos, complexity and shifting world views.

Systems Thinking. Systems thinking recognizes understanding of participants within a system is not possible separate from studying the dynamics of the system. "Systemic properties are destroyed when a system is dissected, either physically or theoretically, into isolated elements" (Capra, 1983, 267). A systems thinking approach to organization avoids fragmentation resulting from studying isolated pieces of an organization, and considers complex relationships and therefore is consistent with the study of nonlinear chaotic systems.

Personal Mastery. Continual growth in open systems relies on the free-flow of energy throughout the system. Personal mastery encourages energy exchange at the individual level by facilitating and nurturing growth. The assumption of the learning organization is the synergy of relationships within the organization contribute to the well-being and growth of the organization itself. Personal mastery is an emancipatory act that allows individuals to adopt the stance that learning is a process with no end, it is a "becoming" rather than a "being" state, and that learning is a continuing and adaptive endeavor. Personal mastery in a learning organization allows for self-organization and therefore is a vital component of the adaptive potential of the individual within the system.

Mental Models. Mental models are 'deeply ingrained assumptions, generalizations, or even pictures or images that influence how we understand the world and take action' (Senge, 1990, p.8). The potential brought forth by participants in an organization is directly related to their models and participation in creating community vision and is essential for the future health and vitality of a learning organization. The evolution of a learning organization is related to its ability to 'learn' which relies on the synergy of shared vision created by a community provided opportunities for constructing their own mental models. Mental models, therefore, are the mechanism for self-organization in community.

Team Learning. Related to mental models are structural characteristics that facilitate team learning and community building. The free flow of energy in open systems includes information exchange and the construction of new knowledge. Characteristic of approaches to New Science, defining characteristics of a system are not the components of which it is comprised but the relationships. Similarly, elemental to learning organizations are the relationships nurtured. Team learning is related to mental models as shared visions are negotiated and consensual vision is constructed. Through the process of negotiation, synergy is accomplished.

How can the characteristics of complex systems discovered by New Science and the application of New Science to business organizational theory inform our efforts to understand the complexity of learning and the dynamics of schooling? The notions of self organization, sensitivity to initial conditions, and self similarity, characteristic features of complex adaptive systems, will be considered to make sense of the school context.

Schools As Complex Adaptive Systems

Schools are open systems with a free flow of energy and information. The lesson of dissipative structures is that open systems must seek higher orders of organization to prevent system death. To maintain viability, students, teachers and schools seek disequilibrium or change as a natural part of becoming. Applying the same vision Prigogine brought to the study of dissipative systems, system structure of schools will be examined from a New Science perspective.

Self Organization and the Purpose of Schooling

What is the purpose of schools? Goodlad identifies four moral imperatives for schooling in the post-industrial age (Goodlad, 1990). Fullan (1993) builds upon this discussion by advocating the role of teachers as catalysts for change. "Each and every educator must strive to be an effective change agent" (Fullan, 1993, 13). The moral imperative for teachers, therefore, relevant to self organization and adaptation in complex systems, is to serve as catalysts for change. As catalysts, teachers have the potential to promote system viability by encouraging adaptive behavior in children as well as adaptation of the organizational structure of the school. What are the requirements for adaptation in an information society?

Boyer (1995) responds to the questions "What do our students need to know?" and "What will it mean to be an educated person in the 21st century?" by replying "[w]e must create in schools a climate in which students are empowered, ... developing one's own aptitudes and interests and discovering the diversity that makes us each unique ... discovering the connectedness of things" (p. 16). Empowering students is precisely providing them with adaptive capabilities. Preparation for participation in the industrial society of the past required a technical approach to knowing. The factory metaphor of schooling, treating knowledge as a commodity to be acquired by students who themselves were products for societal consumption, was sufficient in the closed world of resource-based economics (Arthur, 1990). Information-age society, however, is subject to the laws of increasing returns. Knowing, in such a world, is a process, a becoming, not an end state or product. Several years ago, industry complained that schools were not preparing students for the world of work because industry was spending so much money on retraining. Although partially correct, the role of schools is not to supply students with a body of knowledge to carry them through the rapid changes of a technology world but to provide them with the ability to continue to learn and adapt to the flux or our changing world society. "The abilities to think and present ideas on the one hand, and to work with others on the other hand are being recognized by education and businesses alike as central to the world's future" (Fullan, 1993, 136).

So if the goal of education is to provide students with experiences that will allow them to become lifelong learners, capable of adapting to rapid changes in society, what should become the school curriculum? How do students learn in a social community? What should schools do to promote learning?

Nonlinearity of Learning

As described above pertaining to New Science, sensitivity to initial conditions is related to the connectedness of a system. The nonlinearity of learning relates to how students derive meaning from their educative experiences. Students do not learn in isolation but as part of a learning community. Questions about how learning occurs require examination of learning at both the micro (or individual) as well as the macro (community) levels. The connectedness of the system directly contributes to the potential for the individual to adapt and grow.

Constructivist learning theory and educational research provide support for the claim that learning is complex. Sensitivity to initial conditions is observed when an insignificant-seeming interaction in the classroom is followed by a qualitative leap in understanding for some individual learner. Socially negotiated norms within the classroom community communicate what 'knowledge' is worth knowing. How students internalize classroom experiences and change as a result of those experiences is complex. The model of learning as the piling up of information does not apply to the reality of human experience. Why is it that often unexpected changes in student understanding follow from chance occurrences in the classroom?

Piaget's mental functioning theory described the nonlinearity of learning through the process of accommodation. While assimilation of new information merely represents addition of information to existing mental structures, accommodation signifies change in existing mental scheme. Research in brain physiology also supports the idea that learning is not incremental but is marked by the leaps and bounds of nonlinearity.

Also related to self organization, accommodation is an adaptive process that cannot be 'caused' in the Newtonian sense. Therefore, teacher control over student learning is not possible. How can teachers ever have 'success' in the classroom, given the nonlinear nature of learning in a 'chaotic' environment? The notion of self-similarity found in dynamic systems offers an answer to this question.

Patterns of Self-Similarity in the Classroom

As examined by New Science, self-similarity describes repeating patterns across scales. Hidden beneath the complexity of open systems are patterns of regularity which, in the classroom, can inform the teacher concerning practices and experiences that promote student growth in understanding in a general way.

Although causality cannot be attributed to student learning based on teacher practices, fractal geometry explored by New Science offers insight into how learning and classroom dynamics can be explored. "Fractals, in stressing *qualitative* measurement, remind us of the lessons of wholeness we encountered in the systems realm. What we *can* know, and what is important to know, is the shape of the whole - how it develops and changes, or how it compares to another system" (Wheatley, 1992, 129).

Examining the classroom dynamics and assessing student learning requires a shift away from standardized testing and individual student assessments in artificial settings. Understanding the holism of the learning environment requires examining patterns of relationships and perhaps challenging what we traditionally have accepted as evidence of knowing.

Transforming Schools as Learning Organizations

Technical approaches to knowing are not adequate for capturing the complexity of the classroom, especially with respect to understanding or bringing about changes in schooling.

Study of dissipative structures with the capacity to self-organize reveals "[i]n response to environmental disturbances that signal the need for change, the system changes in a way that remains consistent with itself in the environment" (Wheatley, 1994, 94). New Science and learning organization theory suggest the need to change our own visions of schooling and the methods we use to examine the schooling context. Partners in the enterprise of schooling can become involved in creating a learning organization with characteristic vitality associated with adaptation and change.

Adopting an emancipatory approach to school change requires fundamentally challenging our basic notions of the purpose of schooling and questioning what is important for children to know to survive in the flux of the 21st century. "If we believe in the universe and ourselves to be mechanical, we will live mechanically. ... Believing in a world of fixity, we will fight change; knowing a world of fluidity, we will cooperate with change" (Ferguson, 1980, 146). Creating a learning organization capable of prolonged growth requires confronting our mixed individual mental models of the future and negotiating a new, shared vision. A systems approach, recognizing that closed systems eventually wear down and die, considers the transformation of schooling, not in isolation, but within the dynamic environment which relates schools with other social and political institutions. To many, the vision and creation of schools as learning organizations may seem overwhelming or impossible because of the complex relationships that exist between schools and society; but "[t]he layers of complexity, the sense of things being beyond our control and out of control, are but signals of our failure to understand a deeper reality of organizational life, and life in general" (Wheatley, 1994, 3).

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