LEARNING ABOUT COMPLEXITY SCIENCE

Although new as a paradigm as applied to health care, complexity science is revolutionizing how we see the world. Our traditional views of cause-and-effect assume a linear worldview in which the output of a system is proportional to its input. This predictable perspective derives from an additive model in which the system is the sum of its parts. Such a reductionistic paradigm has dominated medical thought and is the basis for most of our research and statistical methods.

But complexity science says that such Newtonian characteristics are rare in systems composed of diverse, interconnected, adaptive agents. Indeed, reality in such a complex world is dynamic and unpredictable, exhibiting nonlinear patterns. This module will integrate online resources from three complexity science organizations to help familiarize you with concepts and terminology used in complexity science and will describe how complexity science relates to health care and the health care system.

Basics About Complexity Science

To understand what we mean by complex adaptive systems and why complexity science is relevant, we suggest reading the Primer on Complexity Science which follows.

A Complexity Science Primer:

What is Complexity Science and Why Should I Learn About It?

Adapted From**:** *Edgeware: Lessons From Complexity Science for Health Care Leaders*, by Brenda Zimmerman, Curt Lindberg, and Paul Plsek, 1998, Dallas, TX: VHA Inc. (available by calling toll-free 866-822-5571 or through Amazon.com)

This paper is called a 'primer' because it is intended to be a first step in understanding complexity science. In house painting, the primer or prime coat is not the finished surface. A room with a primer on the walls often looks worse than before the painting began. The patchy surface allows us to see some of the old paint but the new paint is not yet obvious. It is not the completed image we want to create. But it creates the conditions for a smoother application of the other coats of paint, for a deeper or richer color, and a more coherent and consistent finish. As you read this primer, keep this image in mind. This paper is not the finished product. Ideas and concepts are mentioned but only given a quick brush stroke in this primer. You will need to look to the other resources in this kit to get a richer color of complexity.

Complexity science reframes our view of many systems which are only partially understood by traditional scientific insights. Systems as apparently diverse as stock markets, human bodies, forest ecosystems, manufacturing businesses, immune systems, termite colonies, and hospitals seem to share some patterns of behavior. These shared patterns of behavior provide insights into sustainability, viability, health, and innovation. Leaders and managers in organizations of all types are using complexity science to discover new ways of working.

Why would leaders be interested in complexity science? In a recent research project with health care executives, we uncovered two inter-related reasons for the interest: frustration and resonance.

> *"At first learning about complexity science and what it suggested about leadership was confusing, even stressful. Once I began to learn it, to understand it, and to discuss it with other professionals, it began to make sense... I really believe in it... In complexity science I'm learning that leaders of modern organizations have got to take on a different roles - especially in this health care revolution."*
>
> *John Kopicki, CEO,*
> *Muhlenberg Regional Medical Center,*
> *Plainfield, NJ.*

There is a frustration with some of the traditional clinical and organizational interventions in health care. The health care leaders in the study said they no longer trusted many of the methods of management they had been taught and practiced. They didn't believe in the strategic plans they wrote because the future was not as predictable as it was depicted in the plans. They saw intensive processes of information gathering and consensus building in their organizations where nothing of substance changed. They were working harder and feeling like much of their hard work had little or no impact. Complexity science offered an opportunity to explore an alternative world view. Complexity science held a promise of relief from stress but also suggested options for new interventions or ways of interacting in a leadership role.

The second "hook" for health care leaders was resonance. Complexity science resonated with or articulated what they were already doing. It provided the language and models to explain their intuitive actions. By having a theory to explain what they 'knew' already, they felt they could get better leverage from their intuitive knowledge and use it more confidently.

Although we are in the early days of deliberately applying complexity science inspired approaches in organizations, we are gathering evidence of leaders applying the ideas to general management and leadership, planning, quality improvement, and new service development. Some of the application projects have generated positive results while others are still works in progress. Complexity science holds promise to have an important impact on organizational performance.

Comparing complexity science with traditional science

Complexity science addresses aspects of living systems which are neglected or understated in traditional approaches. Existing models in economics, management and physics were built on the foundation of Newtonian scientific principles. The dominant metaphor in Newtonian science is the machine. The universe and all its subsystems were seen as giant clocks or inanimate machines. The clocks or machines can be explained using reductionism - by understanding each part separately. The whole of the machine is the sum of the parts. The clockware perspective has led to great discoveries by focusing on the attributes and functioning of the 'parts' - whether of a human body or a human organization. The parts are controlled by a few immutable external forces or laws. The parts are not seen to have choice or self determination. The 'machines' are simple and predictable - you need only understand the few guiding external rules which determine how the parts will behave. There are limits to this perspective when understanding living systems, and in particular human organizations. Clearly humans are not machine parts without individual choice and so clockware is a necessary but not sufficient way of understanding complex systems.

The Newtonian perspective assumes that all can be explained by the careful examination of the parts. Yet that does not work for many aspects of human behavior. We have all experienced situations in which the whole is not the sum of the parts - where we cannot explain the outcomes of a situation by studying the individual elements. For example, when a natural disaster strikes a community, we have seen spontaneous organization where there is no obvious leader, controller or designer. In these contexts, we find groups of people create outcomes and have impacts which are far greater than would have been predicted by summing up the resources and skills available within the group. In these cases, there is self-organization in which outcomes emerge which are highly dependent on the relationships and context rather than merely the parts. Stuart Kauffman calls this "order for free" and Kevin Kelly refers to it as "creating something out of nothing."

Complexity science is not a single theory. It is the study of complex adaptive systems - the patterns of relationships within them, how they are sustained, how they self-organize and how outcomes emerge. Within the science there are many theories and concepts. The science encompasses more than one theoretical framework. Complexity science is highly interdisciplinary including biologists, anthropologists, economists, sociologists, management theorists and many others in a quest to answer some fundamental questions about living, adaptable, changeable systems.

> *"I found a lot of what we did [in management] was really dumb. It was very impersonal. We treated people as if they were one-dimensional. If you figure them out, give them strict rules, put money in front of them, they will perform better...it was very linear."*
>
> *James Taylor*
> *President and CEO*
> *University of Louisville Hospital*
> *Louisville, Kentucky*

From physics envy to biology envy

There has been an implicit hierarchy of sciences with physics as the most respectable and biology as the conceptually poor cousin. Physics is enviable because of its rigor and immutable laws. Biology on the other hand is rooted in the messiness of real life and therefore did not create as many elegantly simple equations, models or predictable solutions to problems. Even within biology there was a hierarchy of studies. Mapping the genome was more elegant, precise and physics -like, hence respectable, whereas evolutionary biology was "softer," dealing with interactions, context and other dimensions which made prediction less precise. Physics envy was not only evident in the physical and natural sciences but also in the social sciences. Economics and management theory borrowed concepts from physics and created organizational structures and forms which tried (at some level at least) to follow the laws of physics. These were clearly limited in their application and "exceptions to the rules" had to be made constantly. In spite of the limitations, an implicit physics envy permeated management and organization theories.

Recently, we have seen physics envy replaced with biology envy. Physicists are looking to biological models for insight and explanation. Biological metaphors are being used to understand everything from urban planning, organization design, and technologically advanced computer systems. Technology is now mimicking life - or biology - in its design. The poor cousin in science has now become highly respectable and central to many disciplines. Complexity science is a key area where we witness this bridging of the disciplines with the study of life (or biology) as the connecting glue or area of common interest.

For organizational leaders and managers, the shift from physics envy to biology envy provides an opportunity to build systems which are sustainable because of their capacity to "live". Living organizations, living computer systems, living communities and living health care systems are important because of our interest in sustainability and adaptability. Where better to learn lessons about sustainability and adaptability than from life itself.

Complexity questions

The questions asked by complexity scientists in the physical, natural and social sciences are not little questions. They are deep questions about how life happens and how it evolves. The questions are not new. Indeed, some of the 'answers' proposed by complexity science are not new. But in many contexts, these 'answers' were not explainable by theory . They were the intuitive responses that were known by many but appeared illogical or at least idiosyncratic when viewed through out traditional scientific theories. Complexity science provides the language, the metaphors, the conceptual frameworks, the models and the theories which help make the idiosyncrasies non-idiosyncratic and the illogical logical. For some leaders who are studying complexity, the science is counterintuitive because of the stark contrast with what they had been taught about how organizations should operate. Complexity science describes how systems actually behave rather than how they should behave.

> *"It is a curious thing... at least for me it has been. It is both mind expanding because of new notions but it also seems like it is affirming of stuff you already know. It is quite paradoxical."*
>
> *James Roberts, MD,*
> *Senior Vice-President,*
> *VHA Inc., Irving, Texas*

Complexity science provides more than just explanations for some of our intuitive understandings. It also provides a rigorous approach to study some of the key dimensions of organizational life. How does change happen? What are the conditions for innovation? What allows some things to be sustained even when they are no longer viable? What creates adaptability? What is leadership in systems where there is no direct authority or control?

What does strategic planning mean in highly turbulent times? How do creativity and potential get released? How do they get trapped? Traditional management theories have focused on the predictable and controllable dimensions of management. Although these dimensions are critical in organizations, they provide only a partial explanation of the reality of organizations. Complexity science invites us to examine the unpredictable, disorderly and unstable aspects of organizations. Complexity complements our traditional understanding of organizations to provide us with a more complete picture.

That is the good news about complexity science. There is also some bad news. Complexity science is in its infancy. It is an emerging field of study. There are few proven theories in the field. It has not yet stood the test of time. But it has become a movement. Unlike some other movements in the management arena, the complexity science movement spans almost every discipline in the physical, natural and social sciences. There is often a huge schism between those who study the world using quantitative approaches and those who use qualitative methods.

> *"Out of nothing, nature makes something. How do you make something from nothing? Although nature knows this trick, we haven't learned much just by watching... [Life's] reign of constant evolution, perpetual novelty, and an agenda out of our control... is far more rewarding than a world of clocks, gears, and predictable simplicity."*
>
> *Kevin Kelly*
> *Out of Control*

Complexity has created a bridge or a merger of quantitative and qualitative explanations of life. It has attracted some of the greatest thinkers in the world including some of the most highly respected organization theorists and Nobel prize winners in physics, mathematics and economics. It has also attracted poets, artists and theologians who see the optimism implicit in the science. By examining how life happens from a complexity perspective, we seem to have increased our reverence for life - the more we understand, the more we are amazed.

Definition of Complex Adaptive System

The next two sections of the paper need a "warning to reader" label. They are filled with the new jargon of complexity science. Each new term is a quick brush stroke in this primer but is explained in greater detail in other sections of this resource kit. For the reader new to the field of complexity, read the next two sections to get the overall sense of complexity science. You do not need to understand every term at the outset to start the journey into understanding complexity.

Complex adaptive systems are ubiquitous. Stock markets, human bodies, forest ecosystems, manufacturing businesses, immune systems and hospitals are all examples of CAS. What is a complex adaptive system (CAS)? The three words in the name are each significant in the definition. 'Complex' implies diversity - a great number of connections between a wide variety of elements. 'Adaptive' suggests the capacity to alter or change - the ability to learn from experience. A 'system' is a set of connected or interdependent things. The 'things' in a CAS are independent agents. An agent may be a person, a molecule, a species, or an organization among many others. These agents act based on local knowledge and conditions. Their individual moves are not controlled by a central body, master neuron or CEO. A CAS has a densely connected web of interacting agents each operating from their own schema or local knowledge. In human systems, schemata are the mental models which an individual uses to make sense of their world.

Description of complex adaptive systems

CAS have a number of linked attributes or properties. Because the attributes are all linked, it is impossible to identify the starting point for the list of attributes. Each attribute can be seen to be both a cause and effect of the other attributes. The attributes listed are all in stark contrast to the implicit assumptions underlying traditional management and Newtonian science.

CAS are embedded or nested in other CAS. Each individual agent in a CAS is itself a CAS. In an ecosystem, a tree in a forest is a CAS and is also an agent in the CAS of the forest which is an agent in the larger ecosystem of the island and so forth. In health care, a doctor is a CAS and also an agent in the department which is a CAS and an agent in the hospital which is a CAS and an agent in health care which is a CAS and an agent in society. The agents co-evolve with the CAS of which they are a part. The cause and effect is mutual rather than one-way. In the health care system, we see how the system is co-evolving with the health care organizations and practitioners which make up the whole. The entire system is emerging from a dense pattern of interactions.

Diversity is necessary for the sustainability of a CAS. Diversity is a source of information or novelty. As John Holland argues, the diversity of a CAS is the result of progressive adaptations. Diversity which is the result of adaptation also becomes the source of future adaptations. A decrease in diversity reduces the potential for future adaptations. It is for this reason that biologist E.O. Wilson argues that the rain forest is so critical to our planet. It has significantly more diversity - more potential for adaptation - than any other part of the planet. The planet needs this source of information and potential for long-term survival. In organizations, diversity is becoming seen as a key source of sustainability. Psychological profiles which identify individuals' dominant thinking styles have become popular management tools to ensure there is a sufficient level of diversity, at least in terms of thinking approaches, within teams in organizations. Diversity is seen as a key to innovation and long term viability.

Many of us were taught that biological innovation was due in large part to genetic random mutations. When these random mutations fit the environment better than their predecessor they had a higher chance of being retained in the gene pool. Adaptation or innovation by random mutation of genes explains only a small fraction of the biological diversity we experience today. Crossover of genetic material is a million times more common than mutation in nature according to John Holland. In essence, crossover suggests a mixing together of the same building blocks or genetic material into different combinations. Understanding this can lead to profound insights about CAS. The concept of genetic algorithms is paradoxical in that building blocks, genes or other raw elements which are recombined in a wide variety of ways are the key to sustainability. Yet the process of manipulating these blocks only occurs when they are in relationship to each other. In genetic terms, this means the whole string on a chromosome. Holland argues that "evolution remembers combinations of building blocks that increase fitness." It is the relationship between the building blocks which is significant rather than the building blocks themselves. The focus is on the inter-relationships.

In organizational terms, this suggests that it is not the individual that is most critical but the relationships between individuals. We see this frequently in team sports. The team with the best individual players can lose to a team of poorer players. The second team cannot rely on one or two stars but instead has to focus on creating outcomes which are beyond the talents of any one individual. They create outcomes based on the interrelationships between the players. This is not to dismiss individual excellence. It does suggest that individual abilities is not a complete explanation of success or failure. In management terms, it shifts the attention to focus on the patterns of interrelationships and on the context of the issue, individual or group.

CAS have distributed control rather than centralized control. Rather than having a command center which directs all of the agents, control is distributed throughout the system. In a school of fish, there is no 'boss' which directs the other fishes' behavior. The independent agents (or fish) have the capacity to learn new strategies and adaptive techniques. The coherence of a CAS' behavior relates to the interrelationships between the agents. You cannot explain the outcomes or behavior of a CAS from a thorough understanding of all of the individual parts or agents. The school of fish reacts to a stimulus, for example the threat of a predator, faster than any individual fish can react. The school has capacities and attributes which are not explainable by the capacities and attributes of the individual agents. There is not one fish which is smarter than the others who is directing the school. If there was a smart 'boss' fish, this form of centralized control would result in a school of fish reacting at least as slow as the fastest fish could respond. Centralized control would slow down the school's capacity to react and adapt.

Distributed control means that the outcomes of a complex adaptive system emerge from a process of self-organization rather than being designed and controlled externally or by a centralized body. The emergence is a result of the patterns of interrelationships between the agents. Emergence suggests unpredictability - an inability to state precisely how a system will evolve.

Rather than trying to predict the specific outcome of emergence, Stuart Kauffman suggests we think about fitness landscapes for CAS. A CAS or population of CAS are seen to be higher on the fitness landscape when they have learned better strategies to adapt and co-evolve with their environment. Being on a peak in a fitness landscape indicates greater success. However, the fitness landscape itself is not fixed - it is shifting and evolving. Hence a CAS needs to be continuously learning new strategies. The pattern one is trying to master is the adaptive walk or capacity of a CAS to move on fitness landscapes towards higher, more secure positions.

The co-evolution of a CAS and its environment is difficult to map because it is non-linear. Linearity implies that the size of the change is correlated with the magnitude of the input to the system. A small input will have a small effect and a large input will have a large effect in a linear system. A CAS is a non-linear system. The size of the outcome may not be correlated to the size of the input. A large push to the system may not move it at all. In many non-linear systems, you cannot accurately predict the effect of the change by the size of the input to the system.

> *"Some people really want to stop controlling, but are afraid. Everywhere things are changing, creating high degrees of uncertainty and anxiety. And the more anxious you are, the more in control you need to be. Making all this even worse, we've bought into the myth that leaders have all the answers. Managers who accept this myth have their levels of anxiety ratcheted up again. ...If complexity theory can begin freeing managers from this myth of control, I think you'll see people a whole lot more comfortable."*
>
> *Linda Rusch*
> *Vice President of Patient Care*
> *Hunterdon Medical Center*
> *New Jersey*

Weather systems are often cited as examples of this phenomenon of nonlinearity. The butterfly effect, a term coined by meteorologist Edward Lorenz, is created, in part, by the huge number of non-linear interactions in weather. The butterfly effect suggests that sometimes a seemingly insignificant difference can make a huge impact. Lorenz found that in simulated weather forecasting, two almost identical simulations could result in radically different weather patterns. A very tiny change to the initial variables, metaphorically something as small as a butterfly flapping its wings, can radically alter the outcome. The weather system is very sensitive to the initial conditions or to its history.

An example in an organizational setting of non-linearity is the huge effort put into a staff retreat or strategic planning exercise where everything stays the same after the 'big push'. In contrast, there are many examples of one small whisper of gossip - one small push - which creates a radical and rapid change in organizations.

Non-linearity, distributed control and independent agents create conditions for perpetual novelty and innovation. CAS learn new strategies from experience. Their unique history helps shape the path they take. Newtonian science is a historical - the resting point or attractor of the system is independent of its history. This is the basis of neo-classical economics and is the antithesis of complexity.

Complex adaptive systems are history dependent. They are shaped and influenced by where they have been. This may seem obvious and trivial. But much of our traditional science and management theory ignore this point. What is good in one context, makes sense in all contexts. Marketers talk about rolling out programs that were effective in one place and hence should be effective in all. In traditional neo-classical economics, there is an assumption of equifinality - it does not matter where the system has come from, it will head towards the equilibrium point. Outliers or minor differences in the starting point or history of the system are ignored. The outlier or difference from the normal pattern is assumed to be dampened and hence a 'blip' is not important. Brian Arthur's work in economics has radically altered this viewpoint. For example, he cites evidence of small differences fundamentally altering the shape of an industry. The differences are not always dampened but may indeed grow to reshape the whole. Lorenz referred to this in meteorology as sensitive dependence to initial conditions which was discussed earlier as the butterfly effect. In economics, in nature, in weather and in human organizations, we see many examples where understanding history is key to understanding the current position and potential movement of a CAS.

CAS are naturally drawn to attractors. In Newtonian science, an attractor can be the resting point for a pendulum. Unlike traditional attractors in Newtonian science which are a fixed point or repeated rhythm, the attractors for a CAS may be strange because they may have an overall shape and boundaries but one cannot predict exactly how or where the shape will form. They are formed in part by non-linear interactions. The attractor is a pattern or area that draws the energy of the system to it. It is a boundary of behavior for the system. The system will operate within this boundary, but at a local level - we cannot predict where the system will be within this overall attractor.

A dominant theme in the change management literature is how to overcome resistance to change. Using the concept of attractors, the idea of change is flipped to look at sources of attraction. In other words, to use the natural energy of the system rather than to fight against it. The nonlinearity property of a CAS means that attractors may not be the biggest most obvious issues. Looking for the subtle attractors becomes a new challenge for managers.

> *"In the past, when managers have tried to implement change, they'd find themselves wasting energy fighting off resistors who felt threatened. Complexity science suggests that we can create small, non-threatening changes that attract people, instead of implementing large-scale change that excites resistance. We work with the attractors."*
>
> *Mary Anne Keyes, R.N.*
> *Vice President, Patient Care*
> *Muhlenberg Regional Mediacal Center*
> *Plainfield, NJ*

CAS thrive in an area of bounded instability on the border or edge of chaos. In this region, there is not enough stability to have repetition or prediction, but not enough instability to create anarchy or to disperse the system. Life for a CAS is a dance on the border between death by equilibrium or death by dissipation. In organizational settings, this is a region of highly creative energy.

Why is complexity science relevant now?

The seeds for complexity science have been around for a long time. The founding parents of complexity science were often far ahead of their time. Why is now the right time for complexity science? More specifically, why is this the time for complexity science studies of human organizations? Turbulence, change, adaptability and connectedness are not new to the late 20th century. There are at least four reasons why now is the time for complexity science:

1. the limit to the machine metaphor
2. the coming together of biology and technology
3. the connections between studies of "micro" and "macro" phenomena,
4. the apparent compressions of space and time.

The first three reasons will be outlined briefly in this section. The last reason, the compression of space and time, will be described in the next section.

Complexity science is a direct challenge to the dominance of the machine metaphor. Since Newton, the machine metaphor has been used as the lens to make sense of our physical and social worlds, including human organizations. The machine metaphor has been a powerful force in creating manufacturing, medical and organizational advances. However, its limits are now becoming more obvious. It is as if we have collectively learned all we can from the machine metaphor and will continue to use that knowledge where appropriate. But we have more and more instances where the machine metaphor is simply not helpful. For example, it does not explain the emergent aspects of an organization's strategy or the evolution of an industry. Complexity science, with its focus on emergence, self-organization, inter-dependencies, unpredictability and nonlinearity provides a useful alternative to the machine metaphor.

In addition to changing the metaphor to interpret events, complexity science is gaining momentum because of the coming together of biology and technology. Biologists are using technology to understand biology, for example, in biotechnology. Computer technologists are using biology to create computer software which has some life-like characteristics. Without the technological advancements, due in part from the machine metaphor, we would not be able to replicate nature's fractal forms, or understand the implicit process rules that allow flocks of birds to move as one, or explain the chaotic heart rates of healthy humans. Complexity science is understandable to us now because of both the advances in technology and the increased respect for biological lessons.

Complexity science brings together the two solitudes of micro-studies and macro-analysis. For example, the micro studies of the human genome and the macro studies of evolutionary biology are coming together with complexity science. The lessons from the micro studies are informing the macro analysis and the lessons from the macro studies are informing the micro. This second learning - the macro informing the micro - has been underplayed in our search for applying Newtonian scientific thinking to life. A Newtonian perspective suggests that the parts can explain the whole. Therefore, the quest is to study the parts in greater and greater detail. Complexity science suggests that the whole is not the sum of the parts. Emergent properties of the whole are inexplicable by the parts. In complexity, studies of natural and human systems are explained by both kinds of analysis - micro (or analysis of the parts) and macro (or holistic analysis).

Murray Gell-Mann, a Nobel Prize winner, discovered and named the quark - clearly a study of micro parts. But his journey of discovery into the tiniest parts led him to a path of holistic understanding and an appreciation for ecology. His book "The Quark and the Jaguar" exemplifies this coming together of the appreciation of the micro and macro analysis. E.O. Wilson, a renowned biologist, argued that we are seeing the confluence of the two major foundations of biology: (1) the molecular basis of life, and (2) the evolutionary basis for human (and ecosystem) behavior. This has profound impacts on our understanding of organizational health. Some interventions are seen to be context dependent - we cannot explain the micro functioning without understanding the macro context. The health of a community or organization impacts the well-being of the individuals within them. Complexity provides us with the opportunity to look at problems with multiple perspectives, studying the micro and macro issues and understanding how they are interdependent.

This section provided some explanations for the complexity science movement in the physical and natural sciences. But there is an additional explanation for its power in social systems - the compression of time and space. The next section describes this seemingly esoteric issue. Some readers may not feel the need to understand the roots of complexity from this perspective and may skip ahead to the section which addresses the paradoxes of complexity.

The compression of time and space

One of the unique dimensions of the late 20th century is the apparent compression of space and time. Why should health care leaders care about something as seemingly esoteric as the compression of space and time? Most of the models of organization, methods to improve performance, and measurement concepts which dominate the management field today were created with the implicit assumption of space and time lags. In other words, they were designed for a world which in many instances no longer exists. When these approaches are tried in contexts where there is this space-time compression, the results are often frustration, stress and lack of improvement. This section of the paper will demonstrate the compression of space in time using examples from manufacturing, banking and health care.

Dee Hock, the founding CEO of VISA, refers to the major impact the compression of time has had in financial markets. In the past, there was an expectation of a time lag (or 'float') between the initiation and completion of most financial transactions. For example, if you purchase an item on credit there is a time lag between when you make the transaction and when the cash is paid to the supplier. We have elaborate systems designed to take advantage of this float. This luxury of a time lag (or 'float') disappears with the use of debit cards or equivalent systems of real-time transfer of funds.

Hock argues this same reduction of time lags happens with information today. We used to have the luxury of a time lag between the discovery of an idea and the application into practice. This time lag is almost non-existent in many aspects of society today. In health care, medical research is reported on (often in 'sound bites' on the news). The public access to medical research has often created a push to put the ideas into application immediately.

An example of a time lag reduction that has had a remarkable impact on manufacturing around the world is the idea of 'just in time' inventory systems. The idea was a simple one, eliminate the need for storing, financing and managing inventories by creating real-time order and delivery systems between suppliers and producers. When the concept was first introduced there were many skeptics. Yet in a very short period of time, this was standard practice in many (perhaps most) manufacturing industries. Just in time inventory changed the relationship between suppliers and producers. It was both facilitated by the improvement in technology and shaped new improvements in technology to get the most benefit from the concept. Boundaries became blurry between what was "in the organization" and what was "outside". Networks were created to minimize the potential problems if a supplier could not provide the needed goods on time. The definition of success for a supplier was altered and new skills of flexibility were needed in the employees and the physical production systems.

Case Study: Time & Space Compression

At a large hospital in Montreal, a change in procedures demonstrates this compression of time and space. Recently the hospital administrators made a decision to eliminate all radiology film from the hospital. Instead, x-ray images were stored in computer files and doctors viewed them on their computer screens. Films which traditionally needed to be handled, processed and delivered through intermediaries were now directly available from the radiology department to the surgeons or other direct service providers. After hearing how quickly and radically this changed the ability of the radiology department to serve the patient care physicians, several hospitals in Toronto are planning to eliminate radiology film. In this example, film and all of its associated people and systems were intermediaries which created both time and space lags between the tests and the reading or interpretation of the tests.

In terms of compression of space, we can now bypass many of the intermediaries in our society. Intermediaries play the role of a bridge between organizations or individuals. When we can access the organization or individual directly rather than through an intermediary, we are again witnessing a compression of space.

The financial service industry is another case where this compression of time and space can be demonstrated. Technology has allowed us to bridge huge distances and create connections which permit simultaneous creation and dissemination of information. We see this reduction of time lags in banking where the currency float of a few years ago has shrunk to a point of being virtually non-existent. Money can be transferred instantly between individuals, organizations and countries. The increased degree of connectedness aided by technology has eliminated some of the intermediaries in our society. One of the banks' prime roles was to be the intermediary between those who had money to loan and those who had need to borrow money. For a price, the banks would match the players. Today, this is becoming less significant. When the information of who has money and who needs money is more widely available, many corporations are bypassing the intermediary role of the bank. This is not unique to financial services. Due to the technology which allows increased connectedness, in many industries one can go directly to the source of the information, product or service.

In our organizations, intermediaries are often layers of management or supervision. Part of their job is to bridge the gap between the providers of service or front-line workers and upper management. Bridging the gap creates time lags in our organizations. These lags provide the information float and hence the luxury (and sometimes the frustration) of time delays. But these intermediary positions are being eliminated in many industries through downsizing. If the positions are eliminated but the role of intermediation and the expectation of float still exist as old mental models, we will simply see over-worked employees trying to fulfill the same roles but with less resources and less success.

"The tendency of people in positions of power is to believe that they can control and they believe in the power of 'let us figure it out.' 'Let's hire the experts, let us sit in a room, figure it out and then it'll happen.' That is a common theme and it's one that I just don't believe in."

James Taylor
President and CEO
University of Louisville Hospital
Louisville, Kentucky

Intermediaries also imply external 'designers' of a system. The designers are distanced from the deliverers of the service. This is a separation of thought and action in both space and time. The planners plan and others implement - a separation in space. The plans are created first and predetermine the action steps to take - a separation in time. Complex adaptive systems have the capacity to adapt and evolve without an external designer. They self-organize without either external or centralized control.

In highly interconnected contexts, where there is a compression of time and space, the assumptions of float, intermediaries and external designers are problematic. Many management models, such as traditional strategic planning processes, are built on the assumptions of float, intermediaries and external designers. When these assumptions hold, the models are relevant and useful. They can improve effectiveness and efficiency in organizations. When the assumptions are invalid, these models can lead to an illusion of control but an actual loss of effectiveness and adaptability.

Some of the paradoxes of complexity

Complexity science is highly paradoxical. As you study the world through a complexity lens you will be continually confronted with 'both-and' rather than 'either-or' thinking. The paradoxes of complexity are that both sides of many apparent contradictions are true.

The first of these paradoxes is that the systemic nature of a CAS implies interdependence yet each of the elements which are interdependent are able to act independently. Interdependence and independence co-exist.

Another paradox in complexity is that simple patterns of interaction can create huge numbers of potential outcomes. Simplicity leads to complexity. CAS operates in a context that is frequently unpredictable; not merely unknown but unknowable. Yet it is the agents' propensity to predict based on schema of local conditions that allow them to act in an apparently coherent manner.

Complexity science is the study of living systems but living systems die. As a metaphor associated with life, it needs to encompass all aspects of the life cycle. Death is part of this cycle. The traditional management literature's depiction of the life cycle begins at birth and ends at decline. Complexity also includes the study of death and renewal.

"As a physician, I learned to think from a biological perspective. When I went into management, traditional organizational theory seemed artificial, foreign to my experience. So when I started studying complexity, I was stunned. Here was a way of thinking about organizations hat compared them to living things. That makes sense to me, intuitively."

Richard Weinberg, MD
Vice President,
Network Development
Atlantic Health System
Passaic, New Jersey

Complexity is a metaphor

A recent article in a popular magazine argued that we needed to distinguish between complexity researchers who were using the 'theory' from those who were using the 'metaphor'. What that statement missed is that all science is metaphor, as Gareth Morgan argues. It is metaphor which shapes our logic and perspective. Metaphor influences the questions we ask and hence the answers we find. A powerful metaphor becomes deeply rooted in our ways of understanding and is often implicit rather than explicit. In biological terms, a metaphor is the schema by which we make sense of our situation.

Complexity science presents a contrast to the dominant scientific and organizational metaphor and thereby challenges us to see what other questions we can ask about the systems we are studying or living within. The metaphor of systems as mechanical or 'machines' has shaped our studies in physics, biology, economics, medicine and organizations. Complexity is about reframing our understanding of many systems by using a metaphor associated with life and living systems rather than machines or mechanical systems. Viewing the world through a complexity lens means understanding the world from biological concepts.

The inquiry continues

It is normal to finish a paper with a conclusion - to end with a summary of the key points and implications. Yet consistent with both the science of complexity and the state of its development, it seems more appropriate to end with questions. The questions can be viewed from five levels of analysis:

1. sector
2. regional network
3. institution or organization
4. division, department or work group
5. individual person

Some of the questions below are aimed at one of the levels but most can be used for any level. We invite you to participate with us in this inquiry as it applies to Your organization or sector health care. **The overall question is, how can complexity science improve management and the health of organizations?**

Some of the other questions to ponder are:

- How does co-evolution impact the role of a leader? If everything is changing and I am part of that change, how do I plan?
- If a CAS self-organizes, what is the job of manager or leader of a CAS?
- Can we use ideas of self-organization to unleash the full potential of our staff?
- Can we create the conditions for emergence as two or more organizations are coming together in a merger?
- What do we have to change to improve the quality of our services and reduce costs? Can complexity science provide us with any insights to this question?
- If an organization is a CAS, what does this imply about strategic planning?
- Can we use insights from complexity to improve the health of communities?
- If the edge of chaos is the area of greatest innovation, how do we stay on the edge of chaos? What are the risks of staying on the edge?
- What organizational structures, designs, processes etc. are consistent with a complexity science perspective? How would implementing these 'complex' ideas improve organizations and the services they offer?
- How can we ensure complexity science enhances and complements proven management approaches? Where and when does complexity science add most value? Where are "traditional" approaches more appropriate?

This article is found on the Plexus Institute website (http://www.plexusinstitute.org/ideas/show_elibrary.cfm?id=150).

In addition, the New England Complex Systems Institute offers a basic overview of complexity science in the chapter titled “Overview: The Dynamics of Complex Systems —

Examples, Questions, Methods and Concepts" and found at the following website http://www.necsi.edu/guide/DCSchapter0.pdf.

Once you understand the basics of complexity science, we recommend reading two articles from the Plexus Institute website that deal with the application of complexity science to health care. The first overview looks at applying complexity science to health care and is titled "Applying Complexity Science to Health and Healthcare" and is found at the following website http://www.plexusinstitute.org/ideas/show_elibrary.cfm?id=257.

The second article focuses on thinking about health care organizations as complex adaptive systems and is included below.

Health Care Organizations as Complex Adaptive Systems

Written by James W. Begun, University of Minnesota, jbegun@csom.umn.edu; Brenda Zimmerman, McGill University; and Kevin Dooley, Arizona State University. June 15, 2002. Revised version forthcoming in S. S. Mick and M. E. Wyttenbach (eds.), *Advances in Health Care Organization Theory* (San Francisco: Jossey-Bass, 2003).

ABSTRACT

From its roots in physics, mathematics, and biology, the study of complexity science, or complex adaptive systems, has expanded into the domain of organizations and systems of organizations. Complexity science is useful for studying the evolution of complex organizations -- entities with multiple, diverse, interconnected elements. Evolution of complex organizations often is accompanied by feedback effects, nonlinearity, and other conditions that add to the complexity of existing organizations and the unpredictability of the emergence of new entities.

Health care organizations are an ideal setting for the application of complexity science due to the diversity of organizational forms and interactions among organizations that are evolving. Too, complexity science can benefit from attention to the world's most complex human organizations. Organizations within and across the health care sector are increasingly interdependent. Not only are new, highly powerful and diverse organizational forms being created, but also the restructuring has occurred within very short periods of time.

In this chapter, we review the basic tenets of complexity science. We identify a series of key differences between the complexity science and established theoretical approaches to studying health organizations, based on the ways in which time, space, and constructs are framed. The contrasting perspectives are demonstrated using two case examples drawn from healthcare innovation and healthcare integrated systems research. Complexity science broadens and deepens the scope of inquiry into health care organizations, expands corresponding methods of research, and increases the ability of theory to generate valid research on complex organizational forms. Health Care Organizations as Complex Adaptive Systems

It is not surprising that the word "system" slips easily into the vernacular of those working in and studying health care organizations, in statements like the following. "Local health care systems are the forerunners of regional systems." "The U.S. health care system is in crisis." "Health systems are consolidating and integrating." While there are many types of "systems" that exist, it is most common for people to invoke the "machine" metaphor when thinking about organizational systems (Morgan, 1997). It is appealing to think of health care organizations, singly and in concert, receiving inputs, transforming them, and producing outputs, such as improved health. This machine metaphor leads to beliefs on how the "system" can be studied: Examine its parts separately, and understand their mechanics. The machine metaphor leads to belief on how the "system" can be improved: If the system is not working as planned, then identify the broken part and replace it. If the system is too costly, then work towards economies of scale. If the system is not working in a coordinated fashion, then tighten the interconnections between parts of the system.

Any model of an organization or an organizational system is in fact an approximation, a simplification of reality. Yet, these models are of utmost import as they shape the way people believe the system works, and hence, constrain the possible ways they think that research can be conducted and that the system can be improved. For example, in light of increasing pressures to cut costs, health care organizations have engaged in a flurry of activity involving mergers, acquisitions, and other forms of structural change. Economies of scales are invoked as input demands are spread over a smaller base of overhead and fixed costs. Using the machine metaphor, the belief is that one can increase the "input" stream without having to increase the size of the machine proportionally.

Yet, thinking of and operating organizational systems as machines have not led to effective organizational research and practice. For example, researchers and commentators both conclude that "Integrated delivery systems clearly have not performed up to our expectations" (Johnson, 2000:3); and "Controlling health care costs continues to perplex providers, as payers exert pressure and new models seem less promising" (*Health Care Review*, 1999). These sentiments are frequently echoed in the arenas of quality improvement, patient safety, and access to care. Linkage, coordination, standardization, rationalization, and vertical and horizontal integration have failed to advance health care delivery to acceptable levels of satisfaction for both internal and external stakeholders. The health care "system" continues to defy control – it is a "machine" that appears to have a mind of its own.

We argue that improvement of health care organizations individually and collectively, and research on those organizations, will be best facilitated by comprehensive application of the metaphor of the system as a living organism, rather than the system as a machine. Such a metaphor is conveyed by the science of complex adaptive systems, which reformulates systems theory in a way that produces a "model" of the organization more closely related to reality. Whereas traditional systems theory (e.g., Senge, 1990) has its roots in explaining the behavior of "dead" systems (complicated electro-mechanical systems), complex systems science is concerned with explaining how "living" systems work. This offers a transformational leap from the crude understanding of systems that developed in the 1960s and formed the basis of a science of organizational systems. The messy, open systems of complexity science are immensely different from the closed, well-behaved systems that were the original focus of systems science.

While health care organizations have been applying systems science of the 1960s and 1970s, systems science has made transformational changes in its understanding of systems. These new insights have yet to be reflected substantially in the practice of health care organizations and the research activities of those studying health care organizations.

In this chapter, we outline the development of complexity science and its major precepts as they apply to organizations. We discuss areas of application to health care, focusing attention on managing complicated relationships among organizations and stimulating change and innovation. The goal of this chapter is to describe what it means to conceptualize health care organizations (and aggregates of organizations) as complex adaptive systems, rather than as traditional "dead" systems. Implications for researchers are emphasized.

Complex Adaptive Systems

Complex adaptive systems (CASs) are omnipresent. Examples include stock markets, human bodies and organs and cells, trees, and hospitals. "Complex" implies diversity – a wide variety of elements. "Adaptive" suggests the capacity to alter or change – the ability to learn from experience. A "system" is a set of connected or interdependent things. In a CAS, the "things" are independent agents. An agent may be a person, a molecule, a species or an organization, among many others. These agents act based on local or surrounding knowledge and conditions. A central body, master neuron, or CEO does not control the agent's individual moves. A CAS has a densely connected web of interacting agents, each operating from its own schema or local knowledge.

All CASs share some features in common. We describe four that are relevant to organizational theory applications. CASs are <u>dynamic</u>, <u>massively entangled</u>, <u>emergent</u>, and <u>robust</u> (Eoyang and Berkas, 1999; Marion and Bacon, 2000).

First, CASs are characterized by their dynamic state. The large number of agents in the CAS, the connections among the agents, and the influence of external forces all combine to result in constant and discontinuous change in the CAS.

Second, relationships in CASs are complicated and enmeshed, or "massively entangled" (Kontopolous, 1993, quoted in Eoyang and Berkas, 1999:317). Many CASs are comprised of large numbers of interdependent parts and influenced by a large number of interdependent forces. In addition to being numerous and interdependent, parts and variables, and their relationships, can be nonlinear and discontinuous. Small changes in variables can have small impacts at some times, and large impacts under other conditions. Conversely, the effects of large changes in variables can vary from negligible to large, depending on the state of other variables.

The agents of a CAS both alter other agents, and are altered by other agents, in their interactions. Feedback loops among agents can generate change or stability in the system, depending on the relationships among the agents. In the case of feedback loops that generate change, two systems that initially are quite similar may develop significant differences over time. Even the same system, after the passage of time, may bear little resemblance to its previous configuration. Because the context for each CAS is unique, and each CAS is context-dependent, each CAS is unique.

Third, CASs exhibit emergent, or self-organizing behavior. As stated by Marion and Bacon (2000:75),

> [C]omplexly structured, non-additive behavior emerges out of interactive networks. . . .[I]nteractive agents unite in an ordered state of sorts, and the behavior of the resulting whole is more than the sum of individual behaviors. Ordered states. . . [arise] . . . when a unit adapts its individual behaviors to accommodate the behaviors of units with which it interacts. Poincare observed this phenomenon mathematically among colliding particles, which impart some of their resonance to each other leading to a degree of synchronized resonance. Interacting people and organizations tend similarly to adjust their behaviors and worldviews to accommodate others with whom they interact. Networks with complex chains of interaction allow large systems to correlate, or self-order.

Applied to human systems, these findings will be quite familiar to sociologists and social psychologists. Humans adjust their interaction based on characteristics of the other parties to the interaction. Extensive communication among large networks of humans can spead norms and create self-ordering structures, such as norms.

A CAS may be sensitive to certain small changes in initial conditions. An apparently trivial difference in the beginning state of the system may result in enormously different outcomes. This phenomenon is sometimes called the "butterfly effect," based on the metaphor derived by meteorologist Edward Lorenz that a difference as seemingly insignificant as a butterfly flapping its wings in Brazil can change the predicted weather in Texas from a sunny day to a tornado. However, this sensitivity has to do with the <u>exact</u> path that the complex system follows into the future, rather than its general pattern. CASs, including the weather, tend to maintain generally bounded behavior, sometimes called an "attractor," regardless of small changes in initial conditions.

As a result, CASs are robust, or fit. They exhibit the ability to alter themselves in response to feedback. Complex systems possess a range of coupling patterns, from tight to loose (Marion and Bacon, 2000). These different patterns help organizations survive a variety of environmental conditions. Loosely coupled structures help "buy time" in response to strong shock. More tightly coupled structures tend to "lock-in" to a response. Although adaptive in the moment, such a response may turn maladaptive as the environment shifts. As a whole, the complex structures provide multiple and creative paths for action. If one pattern of interdependency in a network is disrupted, other units can respond due to their interdependence with the disrupted unit. Robust response means that the complex system can effectively adapt to a wide range of environmental change, giving it "amazing resilience" (Marion and Bacon, 2000:76).

Growth of Complexity Science

Complexity science, the study of complex adaptive systems, does not consist of a single theory, but rather encompasses a collective of theories and constructs that have conceptual integrity among themselves. Complexity science is highly multi- and inter-disciplinary, and its proponents include biologists, chemists, anthropologists, economists, sociologists, physicists and many others in a quest to answer some fundamental questions about living, changeable systems.

Social scientists came to know about and be interested in complexity through a variety of avenues. Perhaps the most important early event was the discovery of "chaos" (Gleick, 1987). Chaos theory presented two propositions that were attractive to social scientists:

- Small, seemingly inconsequential events, perturbations, or changes can potentially lead to profound, large scale change; and
- What appears to be random may in fact have an underlying orderliness to it.

In addition, the word "chaos" itself was something that in a vernacular sense resonated with current reality.

Organization scholars, and in particular organizational change and development researchers, became interested in how chaos explained the way in which organizations changed, or more importantly, how they could be changed, using concepts such as self-organization, emergence, and bifurcation (Prigogine and Stengers, 1984). Whereas the concept of "chaos" had its roots in physics, concepts of self-organization and emergence drew more from the living sciences of biology and chemistry. Much intellectual focus was switched away from chaos – which described a particular type of behavior found in complex systems – to the more basic question of how such complex systems work in the first place. Complexity science today includes contributions from the theoretical areas of artificial intelligence and agent-based systems (e.g., Axelrod and Cohen, 1999), game theory, evolutionary theory (especially neo-Darwinist ideas, including punctuated equilibrium), cellular automata, and computational biology. Books by Waldrop (1992) and Lewin (1992), both titled *Complexity*, solidified this disciplinary hodgepodge under a single semantic umbrella. The biologist and physician Kauffman's (1993, 1995) work provided much of the theoretical basis for the "adaptive" component of complex adaptive systems.

Table 1 summarizes some key, broad differences between complexity science and the science of linear, stable systems. Complexity science emphasis indeterminism rather than determinism, variation rather than averages, and local control rather than global control. Nonlinear rather than linear relationships are the norm, and a metaphor of "morphogenesis" is preferred to a metaphor of "assembly."

Table 1. Complexity Science vs. Established Science

Complexity Science	Established Science
Holism	Reductionism
Indeterminism	Determinism
Relationships among entities	Discrete entities
Nonlinear relationships – critical mass thresholds	Linear relationships – marginal increases
Quantum physics – influence through iterative nonlinear feedback – expect novel and probabilistic world	Newtonian physics – influence as direct result of force from one object to another – expect predictable world
Understanding; sensitivity analysis	Prediction
Focus on variation	Focus on averages
Local control	Global control
Behavior emerges from bottom up	Behavior specified from top down
Metaphor of morphogenesis	Metaphor of assembly

Source: Adapted from Dent, 1999, Table 1.

The natural and physical science foundations of complexity science produce both strengths and weaknesses for organizational researchers (Begun, 1994), and the diffusion of complexity science into academic research is occurring at a slow rate. One reason for the slow diffusion of complexity science is the fact that it exists among traditional scientific disciplines, not within. Academics accustomed to functioning with bounded theories within bounded disciplines resist embracing new cross-disciplinary perspectives, as has been the case throughout the history of science (Kuhn, 1962). The mathematical elegance and sophistication of much of physical science research is a problem for some social scientists, either because of philosophical differences (social systems can't be modeled; physical systems can) or because of a lack of training in the methods, leading to an inability to "trust" or interpret the material. The natural science foundations are a source of attraction for others, particularly those with biological backgrounds, including clinicians, who may be more comfortable extrapolating from natural science. Many of the applications of complexity science to social systems are metaphorical, again a source of attraction to some and aversion for others.

Another reason for slow diffusion is that complexity science is relatively new and is still struggling for legitimacy and institutionalization. Appropriate questions about its relevance to human organizational systems, as opposed to biological and physical systems, remain. As with any body of new ideas, there is a danger that complexity science will be over-generalized, overextended, exploited, and abused by those enamored of everything new. Certainly this process is underway with complexity science and organizations (Maguire and McKelvey, 1999), and it is important to recognize and thwart those tendencies. Goldstein (2000), for example, notes how a "bias for believing that self-organization and emergence are nothing but advantageous for a complex system can be seen in organizational applications," including his own. Atchison (1999:50), commenting on the interpretation of change processes in health care from a complexity perspective, expresses concern about "the current enthusiasm of anything labeled 'complexity science.'" Underneath the hype, however, is a signification and permanent leap in scientific knowledge anchored in the physical and natural sciences.

Applications of Complexity Science to Health Care Organizations

Social phenomena, including organizations, became the subject of investigations using methods and metaphors from chaos and complexity theory early in the 1990s (Eve, Horsfall, and Lee,1997; Goldstein, 1994; Kiel and Elliott, 1996; Priesmeyer, 1992; Stacey,1992; Wheatley, 1992). A growing number of researchers continued to explore extensions of complexity science to the study of organizations, signaled by special issues of the journals *Complexity* (in 1998) and *Organization Science* (in 1999), and the new journal *Emergence* (new in 1999), which is solely dedicated to organizational applications. Applications of complexity science to organizational processes like change and innovation are becoming more common in mainstream outlets as well (e.g., Lichtenstein, 2000; Van de Ven et al., 1999). Also, a large number of books purporting to establish business advantage to those organizations that adopt complexity approaches have appeared (e.g., Lewin and Regine, 2000; Kelly and Allison, 1999). The business models inspired by complexity science generally consist of simulations or agent-based models ("agents" are the central actors in abstract models of CASs) using such tools as genetic algorithms and artificial neural networks to address production-scheduling issues, predict complex outcomes (such as financial market movements), and advanced artificial intelligence applications (Wakefield, 2001).

Comprehensive reviews of organizational applications and extensions, both theoretical and empirical, of complexity science are available elsewhere (Anderson, 1999; Lissak, 1999; Marion, 1999; Stacey, 1999). Extensions of complexity science to health care organizational theory began to emerge in the scholarly literature in the mid-1990s. A series in *Quality Management in Health Care*, for example, examined clinical pathways as nonlinear, evolving systems, and provided associated tools (Sharp and Priesmeyer, 1995; Priesmeyer and Sharp, 1995; Priesmeyer et al., 1996). Marion and Bacon (2000) interpreted the fitness of three eldercare organizations based on a complexity science perspective, emphasizing the larger networks in which the organizations were embedded. Begun and Luke (2001) analyzed organizational arrangements in local health care markets in 1995 as a function of initial conditions in local systems at the precipice of change in the early 1980s. Arndt and Bigelow (2000) speculated on potential applications of complexity science in health management research. Dooley and Plsek (2001) used models of complex natural processes to interpret the generation of medication errors in hospitals and conclude that the recommendations embedded in the Institute of Medicine report (Kohn, Corrigan and Donaldson, 2000) do not go nearly far enough in terms of their ability to generate significant organizational learning and thus improvement. Begun and White (1999) extended the metaphor of complex adaptive system to the nursing profession, noting particularly its inertial patterns and resistance to change.

Contemplating the implications of complexity science for the practice of health care management and leadership, Zimmerman, Lindberg and Plsek (1998) contributed a primer on complexity science, with nine management principles for leadership and management in health care organizations. McDaniel (1997) and McDaniel and Driebe (2001) construed the leadership imperatives of healthcare executives from the perspective of quantum and chaos theory, and applied complexity science to the process of management in health care delivery.

Over the past decade, in sum, the literature demonstrates a diffusion of complexity science applications from social systems in general, to organizational systems, and now to health care organizations. It can be expected that such applications to health care will continue to draw increased attention as more researchers are exposed to the science. To help develop such efforts, next we explore how complexity researchers might approach two specific research topics in health care management.

Key Differences between a Complexity Science Perspective and Established Perspectives

In this section we identify key differences between established theoretical perspectives commonly used in health management research and the complexity science perspective. Established perspectives in health care organization research include those that commonly are found in textbooks, are taught in doctoral programs in health administration and are used commonly in the health care management research literature. A partial laundry list would include the following: resource dependence, transaction cost, agency, structural contingency, population ecology, institutional, and the "hybrid" strategic management perspective. The established perspectives share a number of common traits, summarized in Table 2. Due to some variation within the established perspectives, in Table 2 we restrict judgments about such differences to three established theories: structural contingency, transaction cost, and institutional theory. These three theories have been utilized in a recent journal issue to characterize the nature of change in health care organizations and markets (Stiles, Mick and Wise, 2001; Wells, 2001; Young, Parker and Charns, 2001)

Table 2. A Comparison of Established Perspectives and the Complexity Science Perspective on the Study of Organizations

	Established Perspectives*	**Complexity Science Perspective**
TEMPORAL FRAMING		
VIEW OF THE FUTURE	Relatively knowable	Relatively unknowable
RELEVANCE OF HISTORY	None (transaction cost) to high (institutional). When high, history is deterministic.	High, but history may or may not be deterministic.
SPATIAL FRAMING		
DOMAIN OF STUDY	Reified organization in the environment	Relationships among individuals, subsystems, systems
VIEW OF THE ENVIRONMENT	Outside the organization; evolves separately from the organization	Part of the domain of study; coevolves with the organization; fitness landscapes
LEVELS OF	Single to few, relatively	Multitude of nested levels

ANALYSIS	independent	
CONSTRUCT FRAMING		
STRATEGY	Relatively designed	Relatively emergent
STRUCTURE	Equilibrium; relatively centralized	Non-equilibrium; relatively decentralized
PURPOSE OF ORGANIZATIONAL RELATIONSHIPS	Efficiency, fit, institutional conformity (legitimation)	Learning; co-creation of meaning
KEY INFORMATION FOR THE ORGANIZATION	External environmental intelligence	Functioning of relationships
INFORMATION PROCESSOR	Reified organization	Individuals; complex systems of individuals

**There are a wide variety of established perspectives. We focus specifically on structural contingency theory, transaction cost theory, and institutional theory.*

First, we examine the time orientation of the perspectives. Established theories are based on a view of the future as relatively knowable. Researchers should be able to specify models that allow for reasonable prediction. The complexity perspective assumes the converse, that the future is relatively unknowable. Emergent properties cannot be predicted from a system's individual parts due to the multiple nonlinear interactions and feedback loops among the parts. Historical patterns are an acute source of information in some established perspectives, particularly institutional theory, wherein the role of history is to inform the future. Other established theories, particularly those derived from economics, are largely ahistorical. Complexity science validates the relevance of history to the state of every existing system, although the degree to which systems are history <u>dependent</u> can vary from none to extensive. Importantly, the high relevance of history in the complexity perspective does not remove the expectation that novelty, and transformational change, can emerge in a CAS at any given time. History is highly relevant, but not necessarily deterministic. This, again, reinforces the irrelevance of the prediction of details, or paths (vs. patterns), as a goal of research on CASs

Second, the CAS perspective entails different assumptions about the unit and levels of analysis (spatial framing). Established perspectives typically identify an organization, which we label a "reified organization," as the domain of study. Reification involves the assignment of material reality to an abstract concept. The assumption that the legal entity known as an organization is the most useful unit of analysis is challenged by complexity science. The complexity perspective gives analytic priority to the relationships embedded inside, outside, and around entities within the bounded, reified organization itself. Accordingly, the environment is a construct that has little meaning to the complexity researcher; rather, relationships among organizational entities and environmental entities are the domain of interest. Coevolution of these relationships characterizes change better than the separate evolution of "the organization" and "the environment." Kauffman's (1995) depiction of systems seeking peaks on constantly changing rugged landscapes, and transforming those landscapes and themselves in the process, is a complexity-inspired analogue to the traditional organization-environment relationship. A final difference in spatial framing between the established and complexity perspectives is the tendency of established perspectives to focus on one or a few levels of relatively independent analysis. Complexity science notes the embeddedness of all systems within larger ones, and the need to analyze relationships across levels of systems.

Finally, several differences between "what is studied" by established perspectives vs. complexity science can be further refined. Key constructs are framed differently. According to established perspectives, the strategy of an organization is relatively designed by the reified organization. The strategy of a complex adaptive system, on the other hand, is relatively emergent. Strategy changes in unpredictable ways over time based on learning from relationship coevolution. Structures, concommitantly, are relatively flexible, and there is no "equilibrium" structure. Relationships coevolve for the purpose of learning and the creation of meaningful systems. In contrast, established perspectives assume a reified organization pursuing external environmental intelligence to better fit the organization to the environment or to optimize its economic efficiency within the environment.

We argue that the complexity perspective's operating assumptions are better equipped than established perspectives to yield useful research questions on complex adaptive systems. Conducting research from a complexity perspective requires corresponding methods of research, however, which are far from well-developed.

Consequences of Complexity Science for Research Methods[1]

As might be expected, application of new theories often may require the use of new and different research methods. Novel discoveries and paradigms typically emerge through the efforts of "explorers" (Rogers, 1995); explorers typically represent a minute fraction of the research population. In complexity science, these explorers primarily have come from physics, biology, and mathematics, and have included few social scientists. Explorers are not necessarily overly concerned about context or application. As these novel ideas gain exposure, diffusion proceeds to the "pioneers." Pioneers bring the ideas across disciplinary boundaries, and seek connections between theory and practice. They are open to learning from the explorers, in an interdisciplinary way. Pioneers may be thought of as generalists, and may in fact often lack the specialized skills (or interest) to pursue the intricate details of implementing the ideas into singular domains. Researchers investigating the interaction between complexity and social science currently fall into this category. In order for complexity science to have impact on a particular theory domain, it must be adopted by a majority of researchers and practitioners considered "settlers." Settlers perform the equally important duty of "normal science" (Kuhn, 1962). This group places great emphasis on domain context. They are interested in optimizing an idea to its specific domain application. They tend to learn and communicate strictly within their domain.

Note that it is the pioneering group who is probably most challenged with respect to research methodologies. These new concepts may be difficult to import into the domain, especially when the existing paradigm (collective schema) of the settlers is in opposition. The

[1] *Portions of this section are derived from Dooley and Guastello (1994).*

pioneers must adhere to the rigor expected by the nature of the scientific order, and yet be careful not to get caught in the trap of using the wrong methods to study new phenomena. Pioneers indeed have to invent new research methods alongside their research hypotheses.

The vast majority of research on health care organizations can be classified as "positivistic," which dictates that hypotheses be stated and then subjected to falsification (Popper, 1959:41). Experiments, whether planned or ad hoc (e.g., empirical surveys, case studies), are the essence of such refutation. Some proponents of complexity science contend that striving to fit within the positivistic research framework threatens the transformational nature and potential contributions of complexity science (Stacey, Griffin and Shaw, 2000).

In order for complexity science to be applied in a positivistic framework, it must be capable of generating testable hypotheses. This is difficult for a new discipline, as definitions for basic constructs such as emergence and self-organization are fluid and not well agreed-upon. Even the concept of "chaos" suffers from a dichotomy of meaning (Dooley and Van de Ven, 1999). Further, these constructs must be operationalized into measurement instruments. Currently, perceptual scales for measuring these constructs do not exist, and if measured at all, they are observed via secondary sources. For example, "organizational complexity" may be observed by counting the number of different functional roles present in the organizational chart (Dooley, 2002a).

Causal links in the proposed theory must be tested. Empirical tests of most theories in the social sciences, including health care organizational theories, however, assume linearity and unidirectional causation. The statistical methodologies available to test other model forms is grossly inadequate. Consider a simple theory linking motivation and performance. It is generally agreed to that this relationship is bi-directional, as individual theories support the causal links in both directions (Gallistel, 1990). How could that bi-directionality be proven, though? At the very least, to address bi-directional causality, longitudinal data would have to be planned and collected. Elaborate time series methods would have to be used. Real social systems pose a problem to even this strategy, however. Model parameters are likely to be time varying, a challenge for any statistical methodology. The time lag – the delay between cause and effect – is also likely to be dynamic. Clearly, modeling approaches need to be further developed in order to test multi-causal social systems. One may even conclude that such deductive inquiries are no longer valid.

Qualitative research methods may serve researchers well in disentangling dynamic, complicated, emergent systems. To date, many applications of complexity science to organization have involved multi-method case studies over time. One methodological tool that complexity science does have in abundance is a rich set of poetic metaphors: the strange attractor, the butterfly effect, self-organized criticality, fractal, etc. It is not surprising to see this new language give rise to new creative ideas, and be used to sell "older" ideas in new ways. Metaphors allow the understanding of one concept (or phenomena) in terms of another (Lakoff and Johnson, 1980). They are artificial symbols to assist thought (Turbayne, 1962) and provide "windows into the soul of the social system" (Burke, 1992). When used in a research context, Hallyn (1990:28-29) captures the different uses of metaphor:

> A metaphor does not always have the same status…I shall differentiate a discursive status (valid in the case that aims to enlighten or convince), a methodological status (implying a heuristic function), and a theoretical status (linked to a vision of the world that poses a priori the existence of a real analogy). It is clear that only the two latter types belong in a poetics of the hypothesis. A metaphor is discursive when it is applied to persuasion and exposition. The theoretical status applies especially to… "absolute" metaphors, which are the "first elements of philosophical language, irreducible to the realm of logical terminology."

Much of the current social science research concerning complexity is based on discursive metaphors, e.g. claiming that leadership is a "strange attractor." (A strange attractor is the pattern of a pathway, in visual form, produced by graphing the behavior of certain systems.) This type of research should be expected from the pioneers, who may be less concerned with methodological rigor than the richness of concept these new ideas bring; discursive metaphors can play a powerful role in spurring creativity. Proper discursive use of metaphors still requires proper understanding of the underlying science. Health organization researchers may be in a good position with regards to this requirement, as many have backgrounds in systems theory and/or biology, good backgrounds from which to develop knowledge of complexity science.

Simulation may be an especially productive means by which to pursue the application of complexity science to health care research questions (Dooley, 2002b). Simulations fall into three broad categories: simulations involving human interaction only, simulations whereby the human interacts with a computer, and simulations involving a completely computerized medium. In all cases, the theorist has a complex system in mind and wants to explore what might happen when system variables are systematically varied. System simulations are thus prepared to capture the relevant system behaviors and control extraneous variables whenever possible, and just as importantly, to provide results in a manageable amount of time. The validity of the simulation depends on the assumptions made to simplify the simulation, and the rules chosen to embody action, sense making, and decision-making within the simulation.

A Complexity Science Perspective on Integration and Innovation in Health Care Organizations

To make the comparison between a complexity science perspective and established perspectives more concrete, we examine two domains of health management research and practice that could particularly benefit from a complexity science perspective. The domains are (1) innovation in health care delivery, and (2) structure and performance of integrated delivery systems. The two research domains are not mutually exclusive, but each has a distinctive tradition of theory and empirical research.

Researchers and practitioners in both of these research arenas are deeply affected by the complexity of health care delivery. It is commonly espoused that "The health care field is complex, perhaps the most complex of any area of the economy" (Morrison, 2000:xvii). Complexity is reflected in the number, variety, and fragmentation of producers involved in the delivery of health care: potential patients (who are consumers of prevention), actual patients, professionals, provider organizations, buyer organizations (including large employers who purchase on behalf of employees), insurers or payers, and suppliers. Glouberman and Mintzberg (2001a, 2001b) more abstractly conceptualize extensive differentiation in the health care sector into four "worlds" of cure, care, control, and community. Deep-seated differentiation, in turn, leads to inability to diagnose and design effective interventions for innovation and improvement that rely on coordination and control. This feature of health care delivery complicates decisions about how to structure integrated delivery systems, and the ability to predict their performance. Too, complexity affects the ability of the health care systems to generate diversity and innovation, particularly innovation that is transformational.

Researchers can approach innovation and integration in health care from a variety of established theories or perspectives. In the following discussion, we again use institutional theory, transaction cost theory, and structural contingency theory to represent established perspectives. Complexity science offers a different and potentially more powerful alternative. To frame and bound the discussion of the complexity perspective, we explore research implications of the characterization of complexity science previously given in Table 2. Research implications of each characteristic of complexity science are denoted in Table 3.

Table 3. Research Implications of Complexity Science Perspective

	Complexity Science Perspective	**Implications for Research**
TEMPORAL FRAMING		
VIEW OF THE FUTURE	Relatively unknowable	Patterns may repeat, but without predictive power. Anticipate surprise. Study emergence.
RELEVANCE OF HISTORY	High, but history may or may not be deterministic.	Requisite to study history (vs. cross-sectional only); conduct longitudinal analysis
SPATIAL FRAMING		
DOMAIN OF STUDY	Relationships among individuals, subsystems, systems	Study patterns of interaction among agents.
VIEW OF THE ENVIRONMENT	Part of the domain of study; coevolves with the organization; fitness landscapes	Study coevolution of organization and environment
LEVELS OF ANALYSIS	Multitude of nested levels	View issue from multiple, nested levels of systems
CONSTRUCT FRAMING		
STRATEGY	Relatively emergent	Study changes in strategy and conditions that facilitate

		change
STRUCTURE	Non-equilibrium; relatively decentralized	Assess flexibility of structures; simple rules; min specs
PURPOSE OF ORGANIZATIONAL RELATIONSHIPS	Learning; co-creation of meaning	Assess degrees of co-participation, learning, sharing
KEY INFORMATION FOR THE ORGANIZATION	Functioning of relationships	Study quality of relationships
INFORMATION PROCESSOR	Individuals; complex systems of individuals	Study individuals and coalitions, vs. reified organization

Innovation in Health Care Delivery

Innovation in health care delivery is significant in magnitude and impact. It is estimated that $35.8 billion was spent on the development of new practices and products in health care in the U.S. in 1995 (HCFA and NSF, 2001). Many of these innovations have significant, positive consequences on individual and public health. For example, the DISCERN medical error warning system, a computer-based system that examines a patient's prescriptions for adverse drug interactions, is estimated to have saved numerous lives, and $5.3 million in health care costs, within Banner Health Systems' three Phoenix-based hospitals (Snyder, 2001). Innovative new services are not isolated to specific medical procedures and systems, but extend also into the domain of both integrated health systems and the conduct of public health.

Within the public health arena, much innovation effort has been focused on HIV/AIDS (UNAIDS/WHO, 2000a, 2000b). The Joint United Nations Programme on HIV/AIDS and the World Health Organization estimate that worldwide, some 5.3 million people were newly infected with HIV in 2000, 36.1 million are living with HIV/AIDS, and 21.8 million have died since the beginning of the epidemic. AIDS is especially prevalent in developing countries; Africa has three-fourths of the AIDS-infected population. The general public health in such countries is significantly affected. For example, it is projected that life expectancy in Zimbabwe will be reduced from 63 years in 1985 to 35 years in 2010 (Bonnel, 2000). The epidemic also has severe economic consequences. For example, in South Africa, AIDS is expected to reduce gross domestic product by 17 percent by 2010 (UNAIDS/WHO, 2000a, 2000b).

According to the U.S. Centers for Disease Control and Prevention (CDC), various HIV prevention efforts in the U.S. through the 1990's have reduced HIV seroprevalence by 50 percent within the vulnerable community, by 40 percent within New York City injection drug users, and by 75 percent for babies contracting AIDS from their mother (CDC, 2001). The CDC has broad-based goals of preventing AIDS through decreasing new infections; increasing knowledge of serostatus; increasing the linkages among prevention, care, and treatment; and strengthening monitoring, capacity, and evaluation.

Strategies for the prevention of AIDS generally fall into three categories: access, counseling, and social strategies (Auerbach and Coates, 2000). Prevention has increased as people gain access to condoms (CDC, 1998) and sterile needles (Des Jarlais et al., 2000). Counseling strategies to deal with high-risk behavior have been successful, including in developing countries (Auerbach and Coates, 2000). Social strategies raise peer interaction to a community level through education and awareness programs (Latkin et al., 1996).

General theories of innovation suggest that new approaches to HIV/AIDS prevention should not be formalized or centralized (Damanpour, 1996). Formalization involves specified rules, roles, and procedures; creates an environment of risk aversion and attention to efficiency; and is negatively associated with innovation. Centralization involves the extent to which organizational members have freedom to act on their own accord. Highly centralized systems will tend to stifle creativity, as innovation ideas need to travel up and down an organizational hierarchy before they can be acted upon. In the case of HIV/AIDS, this may suggest numerous, parallel innovation efforts, unhampered by formal government oversight.

The innovation literature also stresses the need for the system to have the absorptive capacity to take innovation inputs and create useful outcomes (Fiol, 1996). This absorptive capacity may be dependent upon prior accumulation of knowledge (Cohen and Levinthal, 1990), the ability of different role players to interact effectively (Souder and Moenhart, 1992), and the structure of social networks within the adopting system (Rogers, 1995). Within developing countries struggling with HIV/AIDS, novel means for diffusing knowledge about protection and care may benefit from a "social" absorptive capacity, in that previous public health innovations have had to struggle with the lack of a mass media-infused culture, and invent creative ways to diffuse ideas and spur adoption (Rogers, 1995).

We next present and discuss a case example of one social system that has faced and addressed AIDS treatment in innovative ways. Then, we discuss the case as the subject of research based on established perspectives and the complexity science perspective.

Brazil AIDs Case

In 1997, the World Bank reported that an estimated 30 million people have contracted the human immunodeficiency virus (HIV), and 90% of those were in developing countries (World Bank, 1997). AIDs in developing countries is often assumed to be an intractable problem, based on five key assumptions:

- *the impact of today's interventions (and prevention efforts) will take a generation or two to play out;*
- the cost of the anti-retroviral drug cocktails is out of reach for poor countries;
- treatment is a luxury poor countries cannot afford, and they opt to focus almost exclusively on prevention;
- uneducated, illiterate patients cannot manage their own complicated drug therapies; and
- meaningful solutions require sophisticated, integrated national health care systems.

Brazil's approach to AIDs challenged all of these assumptions and reversed the spread of AIDs. Brazil's efforts really began in earnest in the early 1990s. By 1994, organizations in Brazil were producing their first generic anti-retroviral drugs. Within five years, Brazil's effort had made a major impact on reducing the spread of the HIV virus. In the 1980s, Brazil was held out as an example of one of the countries worst hit by AIDs. Today, Brazil is touted as a model for developing countries fighting AIDs.

Brazil's annual per capita income is less than $5,000 (Downie, 2001). In the 1980s, South Africa's AIDs problem was not as severe as Brazil's (Darlington, 2000). Today, South Africa's HIV infection rate is 25% whereas Brazil's is 0.6% (UNAIDS/WHO, 2000a). In 1992, the World Bank predicted that Brazil would have 1.2 million AIDs cases by 2000, but the actual count was closer to 0.5 million.

The government of Brazil gives free drugs to AIDs patients. Brazil uses the controversial clause of the World Trade Organization that allows countries to violate patent laws in cases of national emergency (AMA, 2001). Brazil argued that the AIDs epidemic is or could become a national emergency. Estimates of the resulting cost reduction vary, and costs are being further reduced as more and more of the drugs are produced in generic form. At a minimum, the cost of the drug therapy per patient per year is 65% lower than the $12,000 cost in the United States. Some estimate that it could be further lowered to be 90% less than the U.S. cost (Darlington, 2000).

The question implicitly posed in Brazil was not "how can we provide treatment when the drug costs are so high?" but "how can we reduce costs so that we can provide treatment to all who need it?"

Organizations in Brazil chose to use treatment as part of the prevention strategy. When people know they can get treatment, they are more willing to come in to hospitals, clinics or certain non-governmental organizations (NGOs) for tests (Rosenberg, 2001). The situation is not deemed to be hopeless. While patients are there for treatments or tests, they also get information and spread the prevention ideas. Today the bulk of the spending is on treatment, yet the prevention goals are being met. The question implicitly posed was not "with our limited resources, should we focus more on prevention or treatment?" but " how can we achieve our prevention goals while treating all of those currently infected?"

Nurses and other health care workers teach patients how to take the drugs. They use whatever methods they can to communicate the drug routine to their patients. They draw pictures of the sun or the moon to denote different times of day. They draw pictures of food on the labels of the pill bottles for those that need to be consumed with food. In addition, they help the poorest patients link up with NGOs, churches and other organizations that offer free food. In spite of the high illiteracy rate in Sao Paolo, Brazil, the adherence rate for the drug regime is at the same level as in San Diego. In both cities, 70% achieve an 80% adherence rate (Rosenberg, 2001).

Rather than being defeated by the overwhelming challenge, participants in the effective system considered such questions as "What methods of communication will work to convey the drug therapy routine to a patient – even a homeless, illiterate patient?" and "If food is an issue, how can we ensure greater compliance with the routine by linking with charities that can provide food at the right times of day?"

Brazil had an established infrastructure of hospitals, clinics and public health services. However, it was a very patchy, irregular system (Rosenberg, 2001). There were huge differences in the services available across the country and to different segments of the population. Brazil's

AIDs efforts have recognized and strengthened existing connections to do the treatment and prevention work necessary to grapple with AIDs. The efforts have used over 600 existing NGOs and community level care organizations to reach the country's poor. The country now has 133 testing and counseling centers. Health care clinicians work alongside NGOs and other organizations to provide the full range of services needed. "It is a well-organized, well-formulated program that works because the government has managed to integrate the whole society – especially NGOs" (CDC, 2000).

Established Perspectives on Innovation

As a relatively innovative advance in the delivery of health services, the Brazil AIDs case provides a provocative research setting for health organization theorists. Established theoretical perspectives would point researchers in particular directions. Transaction cost theory, for instance, would lead the researcher to address such issues as the costs of information exchange between collaborators: What intra-organizational costs were avoided by the government through utilization of existing networks of NGOs, churches and health care clinics? How were the costs of service reduced for the individual health care organizations and NGOs through collaborating on this national agenda? How is the information flow less expensive in Brazil? What needed to happen to reduce those information exchange costs?

A structural contingency perspective would give priority to assessing the fit between organizational forms and their environment. In particular, did the information processing capabilities of the organizations and network of organizations match the degree of uncertainty in the environment? Did the Brazilian organizational forms have the requisite variety given the uncertainty in the environment? Was there sufficient flexibility in the organizational forms to handle the rapidly evolving environment? Was the optimal level of provider integration achieved via the network of organizations handling Brazil's AIDs crisis, given their reciprocal interdependencies?

Finally, researchers applying institutional theory would investigate current and past institutional structures (e.g., government policy, tax laws, professional norms, societal values) that both enabled and constrained governmental and societal reaction to HIV/AIDS. Institutional theory would study processes whereby the "new" treatment and prevention systems may or may not become permanent. The perspective would suggest studying the strength of the three different forms of institutional effect – imitative, normative, and coercive – on the diffusion of the new practices (DiMaggio and Powell, 1983).

Complexity Science Perspective

The complexity science perspective would lead researchers to be less "surprised" by Brazil's achievements in HIV/AIDS prevention and treatment. While recognizing the overwhelming forces supporting the "old" system, the perspective would lead one to investigate the sources of novelty – the tiny differences that made a big difference in producing the "new" system, contrasted to the forces that allow systems to get "stuck" in sub-optimal solutions and interventions (Kauffman, 1995). How were the histories of the entities in Brazil and the traditions of Brazilian culture used to generate rather than constrain the emergence of new patterns? What were the transforming exchanges, containers, and differences that enabled self-organized solutions to occur (Olson and Eoyang, 2001)? To what extent were "wicked questions" that are crucial in breaking the pattern from previous attractor patterns raised and addressed (Zimmerman, 1991, 1993; Zimmerman, Lindberg and Plsek, 1998)? What were the far-from-equilibrium conditions that induced Brazil's reactions to HIV/AIDS (Goldstein, 1994)?

A wide variety of systems at all levels operate within the Brazil AIDS "system." What are the patterns of interaction that repeat at all scales? Where is there scalar invariance indicating an equation or "simple rule" of interaction that repeats at micro, meso and macro levels (e.g., a rule that "poor people can be responsible for their own health")? And do the dynamics of actions taken for HIV/AIDS prevention and care indicate that the innovation system is being driven by few or many factors? Are these factors acting independently or interdependently (Dooley and Van de Ven, 1999)?

As novelty in complex systems arises without a "big plan," the complexity perspective would suggest that the network of providers dealing with HIV/AIDS prevention and care emerged from multiple and parallel experiments, not under any organization's control (Choi and Dooley, 2000). To what extent was the overall approach "chunked" and modular, and to what extent were "min-specs" (minimum specifications) used (Zimmerman, Lindberg, and Plsek, 1998)?

Complex systems operate through relationships among agents of the system. What were the qualities of the relationships among agents in the system (Goodwin, 1994)? One could examine a variety of relationships, including caregiver-patient relationships, government-NGO relationships, relationships of patients to their disease, and information feedback and feedforward loops. At the micro level, relationships are formed by conversation. How reflective is the discursive content of conversations between workers and patients of the larger cultural system regarding HIV/AIDS prevention and care (Corman, Kuhn, McPhee, and Dooley, 2002)? How are the organizational forms informing and being formed by their AIDs work (as opposed to, how are they adapting to their environment [Zimmerman, 1993])?

While all of the perspectives generate interesting and useful research questions, complexity science broadens the scope and significantly changes the direction of research questions that one might ask about the Brazil AIDS case. Relative to temporal framing of the research (see Table 3), complexity science offers more optimism about the possibility for radical change, and more effectively directs researchers to the potential sources of novelty in the system. Longitudinal analysis is implicit in the research method. Relative to spatial framing, the complexity perspective draws the researcher to study relationships among the entities within and across existing systems in Brazil, rather than only within and among "reified" health care delivery organizations. Specific analysis of the quality, emergence, and outcomes of relationships among individuals, groups of individuals, and organizations is explicit in the complexity approach.

Next we review a second area of research and an associated case, to further illustrate research consequences of the complexity perspective.

Structure and Performance of Integrated Delivery Systems

Vertical and horizontal integration have been favored strategies of business organizations, under certain conditions, throughout history. Waves of consolidation (horizontal expansion and integration) and incorporation of buyer and supplier organizations by a focal organization (vertical integration) occur periodically in sectors of the business economy. Pressures for integration, such as increased competition and regulations to control cost and quality, have led health care organizations to embrace higher levels of integration since the 1970s. Initially, researchers employed theory to argue that integrated systems, under the right conditions, would lead to reduced costs and increased quality of services. In the 1980s vertical integration was viewed as the most promising strategy for positioning health care delivery organizations for the future. The exemplary integrated delivery system (IDS) would combine physicians, hospitals, long-term care facilities, and a payment mechanism under one organizational entity. This exemplar was presented in the literature as the "ideal" structure for health services delivery (Shortell et al., 1996).

In the 1990s, researchers made useful discoveries about the difficulty of both implementing vertical integration and delivering on its promises. Studies concluded that many of the allegedly integrated systems in fact demonstrated few characteristics of "systemness" (Shortell et al., 2000). Case-study based reviews of integrated systems demonstrated the considerable diversity within the organizational form "IDS" and resulted in more realistic depictions of the "unfolding" of IDSs over time (Young and McCarthy, 1999). Researchers empirically sorted the population of IDSs into five clusters of systems and four clusters of networks, with wide variation within the set of IDSs (Bazolli et al., 1999). Attention shifted to the "network" form of IDSs (Savage and Roboski, 2001) and the possibilities of "virtual" integration (Coffey, Fenner and Stogis, 1997). The "promises" of integrated delivery were unfilled, leading to a research symposium in 2001 around the theme, The Failure of Integrated Delivery Systems (Friedman and Goes, 2001).

One such IDS that weathered trials and tribulations in the 1990s was Allina Health System, based in Minneapolis-St. Paul. Its recent history is summarized as follows.

<u>Allina Health System Case</u>

Allina Health System was created by the July, 1994 merger of HealthSpan, a large hospital and physician system in Minneapolis-St. Paul, with Medica, a health plan with 900,000 covered lives. Both Medica and HealthSpan had formally existed for only a short time previous to the merger, but their roots were deep in the community. For example, Medica's 1991 initial partners included Hennepin County Medical Society's managed health plan that had begun as an IPA (Independent Practice Association) in 1975. The roots of Allina's hospital system can be traced back to 1857 (Grazman and Van de Ven, 1996).

The Allina Health System combination was hailed as "The first time since Kaiser (Permanente) that the triumvirate of Doctors, Hospitals, and Insurance have been put together in one place" (Grazman and Van de Ven, 1996:1). Allina Health System had $1.8 billion in 1994 revenues and was the second largest employer in Minnesota after Northwest Airlines. Its strategic rationale was the belief that full vertical merger was necessary to create a unified health promotion strategy, a large capital pool, and stability of long-term planning and investment in such areas as information technology and preventive care. Unlike a joint venture or loose affiliation, the merger promised the alignment of incentives, the ability to bear large-scale risk, the accountability for the health of a population, and the authority to sign contracts with one organizational entity (Young and McCarthy, 1999). The state of Minnesota and a powerful business coalition, the Business Health Care Action Group, were instrumental in spurring consolidation and integration in the Minneapolis-St. Paul market.

Allina was structured with an Executive Office at its head, and three divisions: Delivery Services, which included three metropolitan and several non-metropolitan hospitals, home health and other diversified services; Professional Services, which included 55 physician group practices employing 400 physicians, as well as contracts with some 8,700 other providers; and Health Plans. A President's Council brought together leadership from the three operating groups. As a key part of its vision, Allina strived to be recognized as an innovator in community health improvement. Success in this arena was demonstrated by the 1999 McGaw Prize for Excellence in Community Service awarded by the American Hospital Association.

In its early history, Allina focused on creating a consistent corporate identity across its markets and a highly integrated, economically efficient organization. Internal management attention was devoted to performance measurement systems, including patient satisfaction measurement; major investment in coordinating its information system; and a corporate-wide financial control system. Several physician group practices were purchased, and the difficulties of "aligning" physicians with the health plan and hospitals proved to be a continuing challenge (Bunderson, Lofstrom and Van de Ven, 1998).

By the year 2000, Allina had grown to include 18 hospitals and to generate gross revenues of $2.9 billion (Galloro, 2001b), but trouble was on the horizon. The Minnesota Attorney-General began an investigation into the expenditures of Medica, alleging that Medica engaged in lavish spending on image consultants, executive salaries and perks, and corporate entertaining, and that Medica subsidized similar expenditures in other divisions of Allina. After several months of continuing negative publicity in the local and national press, Allina in 2001 agreed to split off Medica as an independent not-for-profit organization. The Medica and Allina boards were replaced by boards appointed with approval of the Attorney-General, and several top executives in Allina and Medica were replaced. The actions soiled the reputation of "one of the country's most prominent not-for-profit healthcare systems" (Galloro, 2001a). The new leadership of Medica immediately announced a 20% staff layoff (Howatt, 2001), and new Allina leadership denounced the criticized expenditures as surprising and inappropriate (Marcotty and Burcum, 2001).

<u>Established Perspectives on Integrated Delivery Systems</u>

Lessons from Allina's merger and de-merger with Medica can be interpreted from any number of established theoretical perspectives. In analyzing the Allina experience, a contingency perspective would direct attention to inadequacies in the organizational form chosen by Allina in 1994. That form, the fully vertically and horizontally integrated system, was predicated on an elusive future in which capitation would rein. Success of the form required that Allina-affiliated physicians and Medica enrollees would cooperate with "integration" by utilizing only Allina hospitals. In fact, only about 25% overlap was attained between Medica members and Allina hospitals, compared to the 75% estimated as necessary to "reap the benefits of integration" (Galloro, 2001b). From the structural contingency perspective, Allina's problems arose from a strategic choice by Allina's top leadership that may have been reasonable for the environment anticipated in 1994, but which did not emerge as expected.

Transaction cost theorists postulate that loose coupling, via contract, in many cases is more efficient that the more tightly coupled IDS exemplar (Mick, 1990). A transaction cost theory approach would focus on the efficiency of full integration of the health plan and of physicians within a hospital system, and explore the possibility that expected efficiencies never materialized. As a result, for example, there was little evidence of cost savings that Allina could offer, to offset external criticism of its internal spending practices.

Institutional theorists have hypothesized that the IDS movement was largely a mimetic response to pressures for industry conformity (Mohr, 1992). Accordingly, an institutional theory perspective might suggest that the culture of the Twin Cities and Minnesota promoted "progressive" experimentation in health care delivery, and collective solutions to social problems, but that a key element of culture – the community responsibility of non-profit enterprise – was neglected by Allina is its drive for legitimacy in the eyes of employers and health care industry peers. Allina was an early adopter of structural innovation in the healthcare industry, but failed to cultivate other important sources of stability and legitimacy.

As with the Brazil AIDs case, established perspectives provide useful ideas for research on the topic. A complexity science perspective builds on, extends, and deepens understanding of the Allina case.

Complexity Science Perspective

As noted in discussion of the Brazil AIDS case, the complexity perspective's "view of the future" would equip the researcher to interpret the unfolding of Allina not as a major surprise or failure, but more of a natural unfolding of learning about complex relationships. The histories of the entities/agents in the multiple systems would no doubt be relevant to understanding the differences between Allina's hospital, physician, and health plan divisions that created tensions. Mapping the multiple, nested systems covered by Allina Health System rubric would be a major undertaking, with consumers, hospitals, health plans, physicians, the local community, and the State among the major interacting units. Failures at one level (e.g., Allina Health System) may be successes at another level (e.g., consumers, State).

After identifying the key relationships among individuals and coalitions in Allina's internal subsystems and between those individuals and coalitions and external organizations/systems, the complexity researcher would want to understand the quality of each of the relationships. How much participation was there from all parties in the key relationships? In particular, to what extent did physicians and consumers influence the direction of the hospitals and the health plan? Through what entities did the health plan relate to the community? What interests were represented in top management and in setting Allina's and Medica's strategic vision?

A central theme of conventional wisdom on IDS formation is the need to establish a shared mission. Established perspectives generally argue that successful change occurs when people are persuaded to hold the same beliefs. Equilibrium and harmony are equated with success. As argued by Stacey, Griffin and Shaw (2000:5), however, "the very difference managers seek so strenuously to remove is the source of spontaneous, potentially creative change. . . Managers may be struggling to change their organizations in ways which ensure that they stay the same." In this sense, a complexity perspective might speculate that the Allina story, and many other stories of "failed" integration, derive from overstructuration and overcontrol in an uncertain and dynamic environment. The overcontrol results in the stifling, rather than generation, of innovative efforts at creating value for consumers (Zimmerman and Dooley, 2001).

The focus of analysis in complexity research shifts from the externally imposed designs or intents of designers of systems to how things really unfold in systems. Traditional systems thinking has created a vicious cycle of (1) design a system, and (2) when the system does not act as predicted, redesign the system. The assumption is that leaders can control the evolution of complex systems by intentions and clear thinking. Complexity science leads one to ask different questions. For example, when an intended design does not play out as predicted, how do things continue to function? Stacey, Griffin and Shaw (2000:59) refer to this as the potential to "get things done anyway." How do patients continue to get care, and clinicians provide care, despite the machinations of formal organizations? Complexity science focuses on how this "anyway" behavior unfolds through everyday interactions and in spite of the fact that leaders continue to focus on the "systems" that attempt to secure predicted changes.

The original decision to merge Allina and HealthSpan in 1994 could represent bold experimentation by risk-taking executives, and its "failure" re-interpreted as a case of successful learning on the part of the organization, albeit at the expense of damage to the careers of several organizational leaders. Researchers from a complexity perspective would be interested in how Allina's structure and strategy coevolved with other forces. To what extent were individuals and coalitions in Allina resilient and able to "learn"? To what extent was Allina "trapped" by the histories of its component subsystems? In what ways was the emergence of novelty encouraged or discouraged? Why were "wicked questions" challenging extravagant expenditures not raised and fully debated internally?

Applied to the structure and performance of IDSs more generally, complexity science would argue that integration is more effective, and expectations more realistic, when the complex nature of the "integrated" entity is recognized and addressed from the start. Integration of complex entities is more effective if they are allowed to "e-merge" rather than if they are "merged" (Zimmerman and Dooley, 2001). Linenkugel's (2001:8) conclusion that "if you've seen one merger, you've seen one merger" reflects the growing acceptance of the complex nature of integration in health care, as does renewed focus on the process, rather than the structure, of integration (Burns et al., 2001).

Conclusions

In considering the experience of health care organizations and the growth of complexity science in the past two decades, two points stand out. First, health care organizations are a rich field for the study of complex adaptive systems. To date, organizational researchers using complexity science have looked towards the "Santa Fe" school, scholars in evolutionary biology and physics and mathematics, for their inspiration. While the study of the emergence of order in (for instance) ant colonies may provide useful insights, the most complex systems are social systems, and health care organizations are the most complex within that subdomain. If one believes that a science is "pushed" and progresses by studying its most complex problems and situations, then complexity science needs to coevolve its next set of theories with a vigorous examination of health and health care management issues.

Second, complexity science should be well-represented among the perspectives available to health organization researchers interested in furthering contributions to science and to practice. A more realistic view of the future, in which surprise is anticipated rather than shunned; the focus on patterns of interaction rather than reified structures; and the continuing development of new concepts to study the emergence of novelty and the success of distributed control, all combine to produce a powerful addition to the theoretical complement of the health organization theorist.

References

AMA (American Medical Association). 2001. "Brazil May Defy the United States and Make More AIDs Drugs." *Journal of American Medical Association*. HIV/AIDs Resource Center, Reuters Health Information, February 5, 2001. www.ama-assn.org/special.hiv/newsline/reuters/02068951.html

Anderson, P. 1999. "Complexity Theory and Organization Science." *Organization Science* 10(3):216-232.

Arndt, M. and B. Bigelow. 2000. "Commentary: The Potential of Chaos Theory and Complexity Theory for Health Services Management." *Health Care Management Review* 25(1):35-38.

Atchison, T.A. 1999. "Reply." *Frontiers of Health Services Management* 16(1):49-50.

Auerbach, J. and T. Coates. 2000. "HIV Prevention Research: Accomplishments and Challenges for the Third Decade of AIDS." *American Journal of Public Health* 90 (7):1029-1032.

Axelrod, R. and M.D. Cohen. 1999. *Harnessing Complexity: Organizational Implications of a Scientific Frontier* (New York: Free Press).

Bazzolli, G.J., Shortell, S.M., Dubbs, N., Chan, C., and P. Kralovec. 1999. "A Taxonomy of Health Netweoks and Systems: Bringing Order Out of Chaos." *Health Services Research* 33(6):1683-1717.

Begun, J.W. 1994. “Chaos and Complexity: Frontiers of Organizational Science.” *Journal of Management Inquiry* 3(4):329-335.

Begun, J.W. and R.D. Luke. 2001. “Factors Underlying Organizational Change in Local Health Care Markets, 1982-1995.” *Health Care Management Review* 26(2):62-72.

Begun, J.W. and K.R. White. 1999. “The Profession of Nursing as a Complex Adaptive System: Strategies for Change.” Pp. 189-203 in J.J. Kronenfeld (ed.), *Research in the Sociology of Health Care*, vol. 16 (Greenwich, CN: JAI Press).

Bonnel, R. 2000. “Economic Analysis of HIV/AIDS.” *Report from The World Bank*. http://www.iaen.org/.

Bunderson, J.S., Lofstrom, S.M., and A.H. Van de Ven. 1998. “Allina Medical Group: A Division of Allina Health System.” Pp. 602-619 in P.M. Ginter, L.M. Swayne, and W.J. Duncan, *Strategic Management of Health Care Organizations*, third ed. (Malden, MA: Blackwell Publishers).

Burke, W.W. 1992. “Metaphors to Consult By.” *Group and Organizational Management* 17(3):255-259.

Burns, L.R., Walston, S.L., Alexander, J.A., Zuckerman, H.S., Andersen, R.M., Torrens, P.R., and D. Hilberman. 2001. “Just How Integrated Are Integrated Delivery Systems? Results from a National Survey.” *Health Care Management Review* 26(1):20-39.

CDC (U.S. Centers for Disease Control and Prevention). 1998. “Trends in Sexual Risk Behaviors among High School Students—United States, 1991-1997.” *MMWR Morbidity Mortality Weekly Report* 47: 749-52.

CDC (U.S. Centers for Disease Control and Prevention). 2000. *Centers for Disease Control Daily News*, September 22. www.ama-assn.org/special/hiv/newsline/ cdd/091800g3.htm

CDC (U.S. Centers for Disease Control and Prevention). 2001. *HIV Prevention Strategic Plan Through 2005*. January.

Choi, T. and K. Dooley. 2000. “Conceptualizing Supply Networks as a Complex System: Its Meaning, Its Properties, And Managerial Implications.” *Journal of Operations Management* 19:351-366.

Coffey, R.J., Fenner, K.M., and S.L. Stogis. 1997. *Virtually Integrated Health Systems* (San Francisco: Jossey-Bass).

Cohen, W. and D. Levinthal. 1990. “Absorptive Capacity: A New Perspective on Learning and Innovation.” *Administrative Science Quarterly* 35:128-152.

Corman, S., Kuhn, T., McPhee, R., and K. Dooley. 2002. “Studying Complex Discursive Systems: Centering Resonance Analysis of Organizational Communication.” *Human Communication Research*, forthcoming.

Damanpour, F. 1996. “Bureaucracy and Innovation Revisited: Effects of Contingency Factors, Industrial Sectors, and Innovation Characteristics.” *Journal of High Technology Management Research* 7(2):149-173.

Darlington, S. 2000. “Brazil Becomes Model in AIDs Fight.” Reuters NewsMedia, November 7, 2000. www.aegis.org/news/re/2000/re001107.html

Dent, E.B. 1999. “Complexity Science: A Worldview Shift.” *Emergence* 1(4):5-19.

Des Jarlais, D.C., Marmor, M., Friedmann, P., Titus, S., Aviles, E., Derea, S., Torian, L., Glebatis, D., Murrill, C., Monterros, E., and S.R. Friedman. 2000. “HIV Incidence among Injection Drug Users in New York City, 1992-1997: Evidence for a Declining Epidemic.” *American Journal of Public Health* 90:352-359.

DiMaggio, P. and W. Powell. 1983. “The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields.” *American Sociological Review* 48:147-160.

Dooley, K., 2002a. “Organizational Complexity.” In M. Warner (ed.), *International Encyclopedia of Business and Management* (London: Thompson Learning, forthcoming).

Dooley, K. 2002b. “Simulation Research Methods.” In J. Baum (ed.), *Companion to Organizations* (London: Blackwell, forthcoming).

Dooley, K., and S. Guastello. 1994. “Research Methods for Studying Chaos and Complexity.” *Evolving Complexity: Challenges to Society, Economy, and Individual* (Dallas).

Dooley, K. and P. Plsek. 2001. “A Complex Systems Perspective on Medication Errors.” Working Paper, Arizona State University

Dooley, K. and A. Van de Ven. 1999. “Explaining Complex Organizational Dynamics.” *Organization Science* 10(3):358-372.

Downie, A. 2001. “Brazil: Showing Others the Way.” *San Francisco Chronicle*, March 25, 2001. www.aegis.org/news/sc/2001/sc010310.html

Eoyang, G.H. and T.H. Berkas. 1999. “Evaluating Performance in a Complex, Adaptive System (CAS).” Pp. 313-335 in Lissak, M.R. and H.P. Gunz (eds.), *Managing Complexity in Organizations: A View in Many Directions* (Westport, CN: Quorum).

Eve, R.A., Horsfall, S. and M.E. Lee (eds.). 1997. *Chaos, Complexity, and Sociology: Myths, Models, and Theories* (Thousand Oaks, CA: Sage).

Fiol, C.M. 1996. "Squeezing Harder Doesn't Always Work: Continuing the Search for Consistency in Innovation Research." *Academy of Management Review* 21(4):1012-1021.

Friedman, L. and J. Goes. 2001. "Why Integrated Health Networks Have Failed." *Frontiers of Health Services Management* 17(4):3-28.

Gallistel, C. 1990. *The Organization of Learning* (Cambridge, Massachusetts: MIT Press).

Galloro, V. 2001a. "Allina Under Fire." *Modern Healthcare* (March 26):4,14.

Galloro, V. 2001b. "The Big Breakup." *Modern Healthcare* (July 30):4-5.

Gleick, J. 1987. *Chaos: Making a New Science* (New York: Viking Penguin).

Glouberman, S. and H. Mintzberg. 2001a. "Managing the Care of Health and the Cure of Disease – Part I: Differentiation." *Health Care Management Review* 26(1):56-69.

Glouberman, S. and H. Mintzberg. 2001b. "Managing the Care of Health and the Cure of Disease – Part II: Integration." *Health Care Management Review* 26(1):70-87.

Goldstein, J. 2000. "Emergence: A Construct Amid a Thicket of Conceptual Snares." *Emergence* 2(1):5-22.

Goldstein, J. 1994. *The Unshackled Organization: Facing the Challenge of Unpredictability through Spontaneous Reorganization* (Portland, OR: Productivity Press).

Grazman, D. and A. Van de Ven. 1996. "The History of Allina Health System." Working Paper, Strategic Management Research Center, University of Minnesota.

Hallyn, F. 1990. *The Poetic Structure of the World: Copernicus and Kepler* (New York: Zone Books).

HCFA (U.S. Health Care Financing Administration) and NSF (National Science Foundation). 2001. http://grants.nih.gov

Health Care Review. 1999. "An Interview with Merlin I. Olson." *Health Care Review* May:1-4.

Howatt, G. 2001. "Medica Lays Off 20 Percent of Its Staff." *Minneapolis Star Tribune* (November 6):D1,D2.

Kauffman, S. 1995. *At Home in the Universe: The Search for Laws of Self-Organization and Complexity* (New York: Oxford University Press).

Kauffman, S.A. 1993. *The Origins of Order: Self-Organization and Selection in Evolution* (New York: Oxford University Press).

Kauffman, S.A. 1995. *At Home in the Universe* (New York: Oxford University Press).

Kelly, S. and M.A. Allison. 1999. *The Complexity Advantage: How the Science of Complexity Can Help Your Business Achieve Peak Performance* (New York: McGraw-Hill).

Kiel, L.D. and E. Elliott (eds.). *Chaos Theory in the Social Sciences: Foundations and Applications* (Ann Arbor, MI: University of Michigan Press).

Kohn, L.T., Corrigan, J., and M.S. Donaldson (eds.). 2000. *To Err is Human: Building a Safer Health System* (Washington, DC: National Academy Press).

Kontopolous, K. 1993. *The Logic of Social Structure* (New York: Cambridge University Press).

Kuhn, T.S. 1962. *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press).

Latkin, C.A., Madell, W, Vlahov, D., Oziemkowska, M., and D. Celentano. 1996. "The Long-term Outcome of Personal Network-oriented HIV Prevention Intervention for Injection Drug Users: The SAFE Study." *American Journal of Community Psychiatry* 24:341-364.

Lewin, R. 1992. *Complexity: Life at the Edge of Chaos* (New York: Macmillan).

Lewin, R. and B. Regine. 2000. *The Soul at Work* (New York: Simon and Schuster).

Lichtenstein, B.B. 2000. "Self-Organized Transitions: A Pattern Amid the Chaos of Transformative Change." *Academy of Management Executive* 14(4):128-141.

Linenkugel, N. 2001. *Lessons from Mergers* (Chicago: Health Administration Press).

Lissak, M.R. 1999. "Complexity and Management: It Is More than Jargon." Pp. 11-28 in Lissak, M.R. and H.P. Gunz (eds.), *Managing Complexity in Organizations: A View in Many Directions* (Westport, CN: Quorum).

Maguire, S. and W. McKelvey. 1999. "Complexity and Management: Moving from Fad to Firm Foundations." *Emergence* 1(2):19-61.

Marcotty, J. and J. Burcum. 2001. "Allina Leader Agrees Perks Were Wrong." *Minneapolis Star Tribune* (September 87):A1, A9.

Marion, R. 1999. *The Edge of Organization: Chaos and Complexity Theories of Formal Social Systems* (Thousand Oaks, CA: Sage).

Marion, R. and J. Bacon. 2000. "Organizational Extinction and Complex Systems." *Emergence* 1(4):71-96.

McDaniel, Jr., R.R. 1997. "Strategic Leadership: A View from Quantum and Chaos Theories." *Health Care Management Review* 22(1):21-37.

McDaniel, Jr., R.R. and D.J. Driebe. 2001. "Complexity Science and Health Care Management." Pp. 11-36 in M.D. Fottler, G.T. Savage and J.D. Blair (eds.), *Advances in Health Care Management* (Oxford, United Kingdom: Elsevier Science).

Mick, S.S. 1990. "Explaining Vertical Integration in Health Care: An Analysis and Synthesis of Transaction-Cost Economics and Strategic-Management Theory." Pp. 207-240 in S.S Mick (ed.), *Innovation in Health Care Delivery* (San Francisco: Jossey-Bass).

Mohr, R.A. 1992. "An Institutional Perspective on Rational Myths and Organizational Change in Health Care." *Medical Care Review* 49(2):233-255.

Morgan, G. 1997. *Images of Organization*, second ed. (Thousand Oaks, CA: Sage).

Morrison, I. 2000. *Health Care in the New Millennium: Vision, Values, and Leadership* (San Francisco: Jossey-Bass).

Olson, E. and G. Eoyang. 2001. *Facilitating Organizational Change: Lessons from Complexity Science* (San Francisco: Jossey-Bass).

Popper, K. 1959. *The Logic of Scientific Discovery* (London: Routledge).

Priesmeyer, H.R. *Organizations and Chaos: Defining the Methods of Nonlinear Management* (Westport, Connecticut: Quorum).

Priesmeyer, H.R. and L.F. Sharp. 1995. "Phase Plane Analysis: Applying Chaos Theory in Health Care." *Quality Management in Health Care* 4(1):62-70.

Priesmeyer, H.R., Sharp, L.F., Wammack, L. and J.D. Mabrey. 1996. "Chaos Theory and Clinical Pathways: A Practical Application." *Quality Management in Health Care* 4(4):63-72.

Prigogine, I. and I. Stengers. 1984. *Order Out of Chaos: Man's New Dialogue with Nature* (New York: Bantam).

Rogers, E. 1995. *The Diffusion of Innovations* (New York: Free Press).

Rosenberg, T. 2001. "Look at Brazil." *New York Times Magazine*, January 28, 2001, pp. 26-54. www.accessmed-msg.org/msf.accessmed/accessmed2.nsf/iwpList4

Savage, G.T. and A.M. Roboski. 2001. "Integration as Networks and Systems: A Strategic Stakeholder Analysis." Pp. 37-62 in *Advances in Health Care Management*, vol. 2 (London: Elsevier Science)

Senge, P. 1990. *The Fifth Discipline: The Art and Practice of the Learning Organization* (New York: Doubleday/Currency).

Sharp, L.F. and H.R. Priesmeyer. 1995. "Tutorial: Chaos Theory – A Primer for Health Care." *Quality Management in Health Care* 3(4):71-86.

Shortell, S.M., Gillies, R.R., Anderson, D.A., Erickson, K.M., and J.B. Mitchell. 1996. *Remaking Health Care in America*, first ed. (San Francisco: Jossey-Bass).

Shortell, S.M., Gillies, R.R., Anderson, D.A., Erickson, K.M., and J.B. Mitchell. 2000. *Remaking Health Care in America*, second ed. (San Francisco: Jossey-Bass).

Snyder, J. 2001. "Valley Hospitals Use Computer Alerts to Foil Errors." *Arizona Republic,* December 10, 2001.

Souder, W. and R. Moenhart. 1992. "Integrating Marketing and R&D Personnel within Innovation Projects: An Information Uncertainty Model." *Journal of Management Studies* 29:485-512.

Stacey, R.D. 1992. *Managing the Unknowable: Strategic Boundaries between Order and Chaos in Organizations* (San Francisco: Jossey-Bass).

Stacey, R.D. 1999. *Strategic Management and Organisational Dynamics: The Challenge of Complexity*, third ed. (London: Trans-Atlantic).

Stacey, R.D., Griffin, D. and P. Shaw. 2000. *Complexity and Management: Fad or Radical Challenge to Systems Thinking?* (New York: Routledge).

Stiles, R.A., Mick, S.S., and C.G. Wise. 2001. "The Logic of Transaction Cost Economics in Health Care Organization Theory." *Health Care Management Review* 26(2):85-92.

Turbayne, C.M. 1962. *The Myth of Metaphor* (Columbia, S.C.: University of South Carolina Press).

UNAIDS/WHO. 2000a. "UNAIDS/WHO Epidemiological Fact Sheets on HIV/AIDS and Sexually Transmitted Infections," 2000 update (revised).

UNAIDS/WHO. 2000b. *AIDS Epidemic Update*. UNAIDS/00.44E.

Van de Ven, A., Polley, D.E., Garud, R. and S. Venkataraman. 1999. *The Innovation Journey* (New York: Oxford University Press).

Wakefield, J. 2001. "Complexity's Business Model." *Scientific American* (January).

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

Wells, R. 2001. "How Institutional Theory Speaks to Change in Organizational Populations." *Health Care Management Review* 26(2):80-84.

Wheatley, M. J. 1992. *Leadership and the New Science* (San Francisco: Berrett-Koehler).

World Bank. 1997. *Confronting AIDs: Public Priorities in a Global Epidemic* (New York: Oxford University Press).

Young, D.W. and S.M. McCarthy. 1999. *Managing Integrated Delivery Systems* (Chicago: Health Administration Press).

Young, G.J., Parker, V.A., and M.P. Charns. 2001. "Provider Integration and Local Market Conditions: A Contingency Theory Perspective." *Health Care Management Review* 26(2):73-79.

Zimmerman, B. 1991. *Strategy, Chaos and Equilibrium: A Case Study of Federal Metals Inc.* Unpublished doctoral dissertation, York University, Toronto, Canada.

Zimmerman, B. 1993. "The Inherent Drive Towards Chaos." Pp. 373-393 in Lorange, P., Chakravarthy, B., Roos, J. and A Van de Ven (eds.), *Implementing Strategic Processes: Change, Learning and Cooperation* (London: Blackwell Business).

Zimmerman, B. and K. Dooley. 2001. "Mergers versus Emergers: Rethinking Structural Change in Health Care Systems." Working paper, McGill University.

Zimmerman, B., Lindberg, C. and P. Plsek. 1998. *Edgeware: Insights from Complexity Science for Health Care Leaders* (Irving, TX: VHA).

This article is found on the Plexus Institute website
http://www.plexusinstitute.org/ideas/show_elibrary.cfm?id=237

Finally, the Plexus Institute website has a library of materials on complexity science and health care (http://www.plexusinstitute.org/ideas/theme_elibrary.cfm?id=6) that we recommend. These materials deal with a variety of health care topics but are generally written for those with only a basic understanding of complexity science.