KNOWLEDGE MANAGEMENT, ORGANIZATIONAL INTELLIGENCE AND LEARNING, AND COMPLEXITY

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Summary

This theme explores the topics of knowledge management, organizational learning and complexity. At the core of this theme is our knowledge of the increasing complexity of natural and human systems. The theme provides insights into emerging scientific views of the evolution of complexity in the universe. The increasing complexity of human systems is examined via a review of the implications of increasing complexity for scientific understanding and methodologies, for human institutions and for individual humans. The growing demand for managing the knowledge resource and developing learning organizations emanates from the increasing complexity of the social realm. The management of knowledge and learning is thus integral to the creation of human organizations and institutions capable of handling modern complexity. The systems of knowledge management and learning are also essential to developing organizational constructs that employ economic models that are responsive to sustainable development and global ecosystem maintenance. Thus the importance of this theme is evidenced by the intimate connections between increasing global complexity and the human capacity both to manage knowledge and learn from that knowledge, and to develop means for integrating complexity and human knowledge into organizational systems that respect the planet's natural resources and the requirements of sustainability.

1. Introduction

The role of humanity in maintaining the life support systems of our planet must be seen within the natural complexity that exists in our universe and within the human institutional patterns that affect the planet's life support systems. This understanding is essential to an appreciation of the theme of "Knowledge Management, Complexity and Organizational Learning." At first glance, the reader may question the linkage between the three fields grouped in the theme. While knowledge management and organizational learning concern the management and purpose of human institutions and the management of the body of human knowledge, complexity represents a larger universal process that drives much of the natural evolution of the universe. However, the linkage between these three fields of study is quite intimate. In fact, it is the tendency towards increasing complexity in natural and human systems that necessitates the need for managing the knowledge resource of humanity and for developing institutions in which learning is valued and rewarded. In short, the evolving complexity of the human condition requires that humanity better manage its knowledge resources while producing institutions capable of handling the increasing complexity of the challenges faced by individuals, nation-states, and humanity.

Considerable attention in this theme-level paper is devoted to scientific discoveries in the natural sciences. This is due to the fact that these discoveries are responsible for many of the views now emerging concerning social and organizational evolution. Furthermore, these discoveries from the natural sciences increasingly serve as a link with the social and organizational sciences that provide new insights into the commonality of natural and human processes. An improved understanding of these important linkages can aid in the process of understanding the challenges to and the prospects for sustainable development on the planet.

2. Defining Complexity

"Everything is simpler than you think and at the same time more complex than you can imagine".
(Johann Wolfgang von Goethe)

Since it is the tendency toward increasing complexity in the human realm that energizes the need for managing knowledge and for producing "learning organizations," we must first examine and define the concept of complexity. Human beings have attempted to define it throughout human history. Early efforts to understand the complexity of the natural world led to what we now view largely as mythology. For example, if we did not understand the complexity of the earth's weather, rain might be explained, as it was in early Greek mythology, as "Zeus pissing through a sieve." Or, before our recognition of the earth's spherical shape, the planet was seen as a flat plane with edges. The unfortunate soul venturing too close to an edge would suffer the fate of falling off into the unknown of a cosmic abyss.

In contemporary times, however, scientists have begun to make serious efforts to examine the nature of complexity itself. This has led to the recent development of what are now called the "sciences of complexity." These emerging sciences represent multidisciplinary and inter-disciplinary efforts to understand both the nature of complexity and how it has evolved in both natural and human systems. While there is debate as to when this modern effort to examine complexity began, it is clear that a growing number of scientists across the natural, social, and organizational sciences are devoting considerable efforts to understanding the complexity of our world. In many ways these efforts remain in an embryonic stage as scientists attempt to develop a body of knowledge about complexity that can lead to applications of these emerging sciences that can aid humanity and the life support systems of our planet.

One of the greater challenges facing those interested in the sciences of complexity involves the creation of a generally accepted definition of the concept. This has been a difficult challenge, indeed. Some scientists have suggested what is referred to as "algorithmic complexity" as a means for defining what is genuinely complex. This view holds that the length of the mathematical formula required to explain a natural or human phenomenon would serve to define its relative level of complexity (see also "Formal tools for exploring complexity"). This would mean that, for example, the mathematical formula required to define the organization the United Nations would necessarily be longer than the description of a ten-person small business organization. This method for defining complexity however fails when the relative skill of the mathematician involved is considered. In brief, two different scientists may have formulas of varying length for either the United Nations or a small business organization.

Another definition of complexity that has been offered has been labeled "computational complexity." This view holds that the time a computer takes to compute a problem determines the complexity of the system under investigation. One would naturally assume that the computer program required to define the United Nations would require more computer processing time than that required to process the description of a small business organization. This definition also fails however, since a more efficient program of the United Nations might take less computer processing time than a very inefficient and slower computer would take to process the description of a small business organization. Thus definitions of complexity have been hindered by "context dependence," meaning that the type of methodology used will result in the perceived degree of complexity of a natural or human system. Clearly, this situation creates real problems for creating a generally accepted definition of complexity.

One other definition of complexity may serve as the definition that best connects complexity with our understanding of the creation and maintenance of the earth's life support systems. This proposed definition is quite simple. Let us define complexity as the degree of human ignorance of a system. This definition means that the less we understand about how an organism, a planet, or a human being behaves the more complex the phenomenon. In short, medical doctors understand the functions of the kidneys and how they work, but the more complex human brain remains a vast mystery. This definition is critical to our understanding of the earth's life support system because it brings a sense of caution and responsibility to human interactions with the biosphere. We simply do not have a thorough and deep understanding of the intricate workings of the planetary biosphere. While we understand many of the parts of the ecosystem we are not sure how all of these parts fit together. Thus, in many ways we remain ignorant of the planet that houses humanity. This ignorance and thus the complexity of our planet require that humanity proceed with caution when we degrade the air and denude the forests. We simply do not know what might happen and when, if we continue to treat the planet as if it is immune to the excesses of industrialization and expanding human populations.

Contemporary students of the sciences of complexity have though established a set of rules that seem to define how complex systems behave (see also “General features of complex systems”). These behavioral rules are nonlinearity, emergence, and self-organization. Nonlinearity refers to the capacity of natural and human systems to generate amplified effects (see also “Mathematical structures of complexity”). This is a result of the disproportionate relationship between cause and effect, which means that seemingly small causes can generate large effects. The often used metaphor that “the flap-ping of a butterfly’s wings in China may cause a tornado in the United States” explains this point. We also know that, as Jay W. Forrester has noted, “we live in a highly nonlinear world.” In nonlinear systems the relationship between variables may not be stable, thus providing the potential for change and surprise. The nonlinearity of complex systems thus also raises a cautionary note concerning the implications of the human/environmental interaction. What might seem like a relatively small disruption to the environment could lead to large global consequences. The global AIDS pandemic is such a case in point. The pandemic has spread globally and in large proportions and represents how nonlinearity can lead to large-scale problems requiring global efforts for solutions.

The concept of emergence refers to the fact that complex systems can generate new and unique forms of behavior and structure. For example, if we consider a human organization as a complex system we know that such organizations create new forms and structure sometimes without human intent. The process of evolution creates emergent form and structure as speciation occurs, leading to the novelty that occurs in nature. Emergence thus is necessary for the creation of novelty in human and natural systems, and also suggests that surprises are a basic component of human and natural systems. Quite often, we simply cannot predict the outcomes of human actions, even if these actions are well intended. As the disproportionate effects of nonlinearity emerge, humans must often simply watch events unfold. This understanding again raises a cautionary note about humanity’s responsibility for sustaining the planet’s life support systems. We simply cannot be sure what will emerge from human interaction with the environment. The reality of our world is that this is a fundamental component of the human condition. This point also emphasizes the importance of both properly managing humanity’s knowledge resources and building human organizations and institutions that enhance learning. Only by better organizing what we know and how we produce learning can we hope to handle the complexity of the human/environmental interaction.

A final common behavioral element of complex systems is self-organization. This term refers to the ability of natural and human systems to break-up during periods of instability or crisis and reformulate into their previous structure and in some cases produce novel forms. What we see as complex systems, whether they are fisheries that have been decimated by over-fishing or human organizations that survive and are rejuvenated after crises, seem to possess the capacity to renew themselves. At the human organizational level, consider how the nation-states of Japan and Germany have managed to renew themselves after the devastation of the Second World War. Critical to this understanding is the closely aligned concept of autopoeisis. This term, first presented in 1973 by the Chilean biologists Humberto Maturana and Francesco Varela, refers to the ability of living systems to constantly renew them-selves and maintain this process such that their structure and integrity is sustained. Consider that the human body is constantly replacing cells throughout the body necessary for survival. Or, consider that an octopus after suffering a detached tentacle can grow a replacement tentacle. What becomes essential in either self-organization or autopoeisis is the "process" of self-renewal. A more detailed knowledge of these processes of self-renewal may help humanity better cope with the challenges of maintaining the earth's life support system. Knowledge of self-renewal thus has the potential to help us better handle both ecological challenges and the challenge of improving the material conditions of the great mass of humanity.

3. The Evolution of Complexity in the Natural Realm

"You cannot reverse the evolution of the universe, even theoretically. And you cannot predict its future, except in terms of scenarios that depend on never-ending series of … crossroads in the chain of causality" (Ilya Prigogine).

To fully understand the intimate connection between complexity, knowledge management and organizational learning we must trace the evolution of complexity on our planet. It is this process of evolving complexity that places humanity in its current dilemma concerning issues of sustainability and maintenance of the earth's life support system. By fully understanding this historical process of the increase of complexity on our planet we begin to appreciate not only how the need for knowledge management and organizational learning has arisen, but also why these human institutional needs are necessary for enhancing and promoting sustainability.

From the beginnings of the known universe, created by the "Big Bang," we can trace the evolution of complexity in the universe. The simple fact that the result of the Big Bang was the formation of multiple galaxies and, in our own solar system, multiple planets shows an inherent tendency toward organization in the universe (see also "Hierarchy and complexity in physical systems"). While the ancients often saw the universe as ruled by the horror of Chaos, modern science focuses on the general patterns within known systems. It is the recognition of these patterns that has also energized the contemporary sciences of complexity as scientists across a variety of disciplines search for similarities across natural and human systems. Just as the ancients wondered about their place and role in the universe, contemporary scientists wonder about what properties and principles of nature have created the amazing array of natural systems and human cultures that have evolved on our planet.

Prior to the twentieth century, Western science was largely dominated by the worldview of the remarkable genius of Sir Isaac Newton (1642–1727). Newton's scientific worldview saw the universe as predictable and orderly. His recognition that planetary motion could be tracked and planetary locations predicted with mathematical accuracy revealed to him that the universe was a rather orderly and mechanical province. For Newton the world functioned much like a clock: mechanical, predictable and stable. This led Newton to the view the dominant force in the universe was equilibrium, or stability. In this mechanical universe change was rare and the maintenance of order the primary goal. Newton's view helped to generate the notion across all of the natural sciences that stability, order, and organization represented the known universe. The natural realm was surely a predictable one.

In the nineteenth century another important discovery profoundly shaped scientific thought. This was the discovery of the Second Law of Thermodynamics, now often referred to as the entropy law. This view holds that closed systems, those without energetic input from the external environment, will tend over time toward disorder. Organized and closed systems, in short, will eventually decay into disorder and disorganization. This process of decay is a process embodied in time. Time becomes the enemy since time serves to denigrate living and non-living things. The apparent universality of the Second Law of Thermodynamics would also lead to the death of the universe as it loses heat and energy and decays into a frozen lifeless mass. This tendency toward the heat and energy loss of entropy would eventuate in a static equilibrium devoid of life and form.

Scientific discoveries during the twentieth century however forced a reconsideration of both the Second Law of Thermodynamics and of the Newtonian notion that balance and order were necessary for the maintenance of our universe. What these discoveries revealed was that the Second Law and Newtonian mechanics worked well when applied to simple and closed systems. However, when scientists began to examine more complex and open systems that were open to energetic input from the external environment, they discovered that these systems behaved in very different ways from those the Second Law or Newton's mechanics would suggest. The human body, for example, is an open system in which humans require food, water, and oxygen from the external environment for survival. Thus, while Newton's mechanics and the Second Law helped to explain the nature of simple mechanical systems, these approaches provided little help in understanding the behavior of more complex systems. As twentieth-century scientists began to examine complex and open phenomena such as the earth's meteorological system or the dynamics of human groups, the work of previous centuries seemed to provide little guidance.

A seminal discovery in the twentieth century that forced a rethinking of both Newtonian mechanics and the Second Law of Thermodynamics was the study by physical chemist Ilya Prigogine (1917– present; Nobel Laureate in Chemistry, 1977) of chemical systems open to their environments, which he labeled dissipative systems (see also "Complexity in chemical systems"). Prigogine discovered that when certain chemical compounds were pushed to a state of instability or disequlibrium, both internal and external disturbances would amplify nonlinear interactions, and push the compounds to a state of disorder such that the organization and structure of the compounds broke apart. These compounds could then evolve in varying ways, one of which was towards disorder and decay. Yet, in some cases Prigogine found that over time these compounds would reorganize into new and unique structures.

In short, what Prigogine had discovered was one of the founding principles of the concept of self-organization. Through both internal and external disruptions to the chemical compounds, these compounds would move through periods of profound instability and disorder, or cascades of chaos, but somehow reach new forms of structure and organization. Prigogine labeled this phenomenon "order through fluctuation." This discovery had a profound effect on students of the sciences of complexity. Prigogine showed that natural systems have the potential for profound renewal and recreation via a process of destabilization and reformulation. Thus, the process of destabilization and disorder did not necessarily lead to decay and destruction. Instead, disequlibrium could lead to new forms of organization and structure.

A graphical method for understanding the processes Prigogine enumerated can be seen in Figure 1. This figure is referred to as a "bifurcation diagram" and is commonly used in the complexity sciences to display the evolution of complex systems. As the branches on the diagram move towards greater complexity and away from equilibrium, these branches increase. At the nexus of each branch is a point referred to as the "bifurcation point." At each of these bifurcation points complex systems cascade through periods of instability and disorder before new and different evolutionary pathways develop. What is also of interest in Figure 1 is that each of the curved lines between bifurcation points can be seen as periods of relative stability. The most remarkable aspect of the diagram is that the periods of stability become shorter and shorter as complex systems evolve through the process of bifurcation. Thus complexity breeds greater complexity by increasingly short periods of stability punctuated by bifurcation points leading to instability and potential qualitative change in the complex system. The metaphor of the bifurcation diagram has profound meaning for studies of complex systems since it shows that the evolution of complexity is a continuous phenomenon generated by instability and symmetry breaks that lead to new forms of behavior and structure.

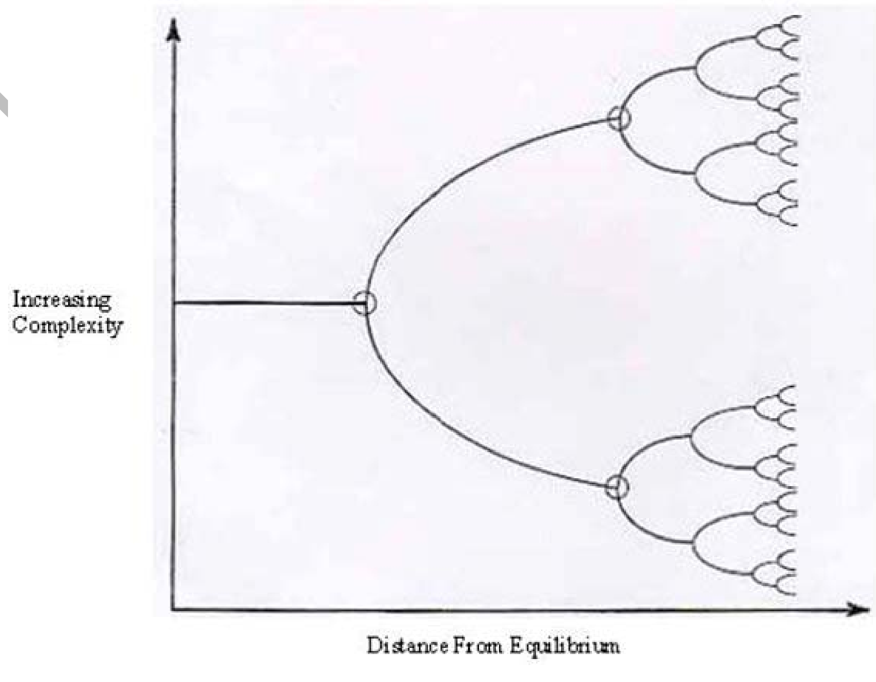

Figure 1: Bifurcation Diagram

Figure 1 thus provides a graphical means to show Prigogine's insights into the functions of instability and disorder in complex systems. Instability and disorder can thus potentially lead either to greater order and organization or towards increased decay and greater disorganization. Moreover, Prigogine's work showed that uncertainty was a critical element in the evolution of living systems. It is uncertainty that provides the multiple possibilities, the openness that generates the potential for fluctuations, bifurcations, and positive change. Yet, in an uncertain world we also lose the confidence that human action will always be for the better.

This understanding has profound meaning for the sustainability of planet earth. The uncertainties inherent in the human/environmental interaction may lead to pathways of environmental stress and decay that limit the planet's capacity for sustaining life. At the same time, humanity's place as both the "conscious animal" and the "technological animal" places us in the ethical position of moving the earth toward a more complex pathway. This is a pathway that ensures that humanity properly manages the planet's resources and its capacity to sustain life.

4. The Self-organizing Universe: Perpetual Novelty in the Natural World

"…the Second Law of Thermodynamics only applies in an equilibrium state. And we've now demonstrated the universe is in a radically non-equilibrium state. The universe is not falling apart. It's enthralling, creative, participating. And life is a natural outcome of a creative universe. We are part of an unfolding universe of increasing complexity in which living things have co-evolved with other living things, mutually make livings together, are functionally coupled and mutually unfolding" (Stuart Kauffman).

Prigogine's work showed how new forms of order could be created in the world of chemical systems. But there is more to the story of evolving complexity in the natural world. Western scientists since the time of Charles Darwin have seen the process of natural selection as the primary driving force in the evolution of living systems. Those species most well adapted to their environments would likely survive, and random mutations could lead to new species better adapted to their environs. Yet Darwinian evolutionary theory did little to help understand the apparent increase in the complexity of living things, from protozoans to amphibians to mammals.

Developments in the modern sciences of complexity have however forced a rethinking of Darwinian theory. At the forefront of this new thinking is the work of Stuart Kauffman. Kauffman was interested in how order and structure are created in living systems. He was not convinced that the process of random mutations alone would generate the amazing array of structures in the natural world, ranging from phenomena such as the starfish to the human brain. He began to recognize that neither complete order and stability nor complete chaos and instability would be likely to generate new form and structure in living systems. Complete order and stability would lead to equilibrium and resistance to the formation of new structure, while complete chaos would never stabilize adequately to produce the amazing structures we see from reindeer to polar bears. Kauffman came to the realization that some midpoint between order and chaos was necessary for living systems to maintain an adaptive response to their environment. This midpoint was labeled the “edge of chaos.” Scientists thus now see the edge of chaos as an adaptive mechanism in which living matter can maintain its existing form and structure but also maintain adequate instability to adapt and change to new circumstances. By residing at the edge of chaos, living systems maintain the potential for adaptive response and increasing their complexity and fitness in the world. Thus the process of evolution includes elements of both Darwinian theory and an apparent natural drive toward increasing complexity (see also “The science of self-organization and adaptivity”).

The story of the evolution of complexity paints an amazing picture of both the order and disorder in the natural world. While Prigogine and Kauffman’s work revealed the functional aspects of disorder and instability, insights produced by Benoit Mandelbrot revealed the inherent order that exists in a creative universe. In the 1960s, Mandelbrot was investigating stock market prices. In the course of these studies he noticed that some stock price graphs looked rather similar whether the graph contained data for a year or for a week. This phenomenon led to Mandelbrot’s further studies of what are labeled scale invariance or self-similarity.

Furthermore, while the data at each level, a year or a week, appeared irregular, the similarity between the time frames was haunting. Thus, while there was irregularity at the local (small) level there was order at the global level (across levels). This knowledge led to the development of what Mandelbrot called fractals. The word fractal stems from the Latin, *fractua*, meaning fractured or irregular. Yet somehow these irregular shapes created structure. It was not the smooth lines of Newtonian geometry and calculus but rather irregular shapes that seem to constitute the natural world. Imagine the coastline of a nation or the structure of a tree. The boundaries that comprise continents, trees or clouds are irregular, yet the structure of continents, trees and clouds is apparent. While there is irregularity in nature there is also commonality.

Imagine that you have three pictures in front of you. These three pictures are a sea sponge, a head of cauliflower and a human brain. Quite amazingly, these three objects are similar in structure and detail. This understanding leads to the inevitable conclusion that there must be some underlying process that creates structure in the natural world. And, if such structure exists then, what are the underlying mathematics that create this structure? In the future, scientists will clearly devote more attention to the mathematics that create structure in the natural world. Scientists have already developed mathematical models that form the structure of the human lungs on a computer screen.

These insights reveal how discoveries in the sciences of complexity have led to our knowledge of a self-organizing universe. These discoveries focus on both order and disorder in the universe and on the increasing complexity and similarities across universal processes, and have led to a new paradigm in the sciences – the self-organizing paradigm that focuses on how form and structure are produced in a dynamic and creative universe (see also “The self-organizing universe”). Thus evolution is fundamentally about the evolution of complexity. Scientists now see the universe as driven by numerous forces that strive to create complexity through the processes of self-organization.

The above noted discoveries involving the evolution of complexity in the natural sciences are beginning to shape a new paradigm in our understanding of the social realm. Furthermore, insights from the natural sciences concerning the evolution of complexity are beginning to shape human understanding of the importance of knowledge in the evolution of social systems, and of the essential requirement for humanity to develop institutional arrangements in which learning becomes a dominant value.

5. Coping with Complexity: The Historical, Social, and Human Implications of Complexity

"I think the next century [the twenty-first century] will be the century of complexity" (Stephen Hawking).

Complexity breeds complexity. Just as the natural world has evolved toward greater complexity, so too has the human realm. Any cursory review of human history shows that human societies have become more complex over time. Of course, complex societies have always existed, ranging from the ancient Roman Empire to the once long-standing Chinese feudal system. Clearly, at the peak of its imperial power, ancient Rome was a complex society. Yet complexity must thus be seen as a relative term. Ancient Roman society would not be considered complex relative to contemporary highly technological and industrialized societies such as the United States or Japan.

While the general trend of social evolution is toward greater complexity, it is necessary to recognize that, just as with biochemical fluctuations, the path of societal and cultural evolution does not mean that complexity will always generate greater complexity. Social systems can fall back to less complex states. The decline of ancient Rome and the onset of the "Dark Ages," the term used to describe early medieval Europe, show that societal complexity can be decreased or inhibited. What is clear, though, is that complexity tends to breed more complexity (see also "The implications of complexity"). Looking back to the bifurcation diagram depicted in Figure 1, we can see that this model also serves as a metaphor for the general evolution of human cultures on our planet. Human culture may evolve toward increased complexity or fall back to less complex forms. Figure 1 also provides insight into the speed of change in an increasingly complex world. Note that periods of stability are increasingly short as human society moves further away from equilibrium. These shortened periods of stability in which increasing bifurcations appear represent a major challenge of complexity.

It is also important to understand that human societal evolution is differential. This means that as some societies increase in complexity other societies may decline in complexity, or remain stable and fundamentally the same for centuries. This explains the fact that human societies across the globe vary greatly in their current levels of complexity. This differential evolution of societies, in part, explains the contemporary use of such terms as the "developed world" or the "Third World." Figure 1 also provides insight into the differential evolution of human cultures. While some cultures evolve toward higher levels of complexity, others fall further into states of equilibrium and minimal complexity.

Table 1 maps the essential societal elements of the four generally recognized historical eras in human social evolution. It helps us to understand the general stages of human sociocultural evolution and the differential nature of this evolutionary process (see also *"Complexity rising: from human beings to human civilization, a complexity profile"*). Thus, in the original hunter-gatherer stage of human evolution we can see that the basic need of those human groupings was the basic physical survival of the kinship group. Protection was maintained by exploiting the dominant resource of land for food and shelter and by the dominance of a charismatic or physically powerful leader who was capable of holding the kinship group together.

Historical Eras

Dominant Cultural Artifacts	**Hunter-Gatherer**	**Agricultural**	**Industrial**	**Post-Industrial**
Basic Human Needs	Food And Shelter	Safety	Esteem	Realization
Dominant Technological Resource	Human Manual Labor	Animal Labor	Mechanization	Automation And Compunications
Dominant Social Resource	Land	Land	Money	Knowledge
Dominant Societal Challenge	Survival	Stability	Mass Production	Complexity
Natural Resource Demands	Local Exploitation	Fertility	Extraction	Sustainability
Pace Of Innovation	Glacial	Incremental	Punctuated Incrementalism	Rapid And Continuous

Table 1. Human Historical Eras and Dominant Cultural Artifacts

The rise of post-industrial society, often referred to as the knowledge-based or information society, represents the latest stage in the evolution of human sociocultural systems. Post-industrial society is defined by the automation of production through the computer–communications technology nexus (see also "Complexity and technology"). Knowledge becomes the dominant social resource as a means for creating greater social complexity and adaptiveness in an increasingly complex world. Yet knowledge as the critical socio-economic resource becomes a unique resource due to its intangibility relative to the dominance of the previous sociocultural resources of land and money. In post-industrial societies, where the material needs of the great masses are generally satisfied, a powerful human need emerges to "realize" each individual's potential both economically and psychologically. Innovation via the organized use of the knowledge resource becomes the basic operating model of these societies (see also "Complexity and innovation"). Consistent with knowledge as the critical resource is the development of learning to produce and use this knowledge. This reality generates a need to create dynamic "learning organizations" in which the learning of all organizational actors is enhanced and used.

Interdisciplinarity and complexity. Scholars across the natural and social sciences are increasingly cognizant of the meaning of the evolution of complexity for all scientific studies (see "Complexity and interdisciplinarity"). There is growing recognition that the same processes that lead to a self-organizing universe have also led to the tremendous complexity of human cultures and human affairs. A growing number of scholars now also realize that the same evolutionary processes that created life on this planet and led to the evolution of *Homo sapiens* also served to create the human brain and the variety of human cultures. It now appears that the concepts of disequilibrium, instability, and order through fluctuations are relevant to the dynamics of all social and human systems. The applicability of these concepts to the dynamics of change across a wide variety of human social and behavioral systems necessitates an interdisciplinary perspective in complexity studies.

Another essential element requiring interdisciplinary investigation in complexity studies is the concept of holism. The oft-quoted aphorism that the "whole is greater than the sum of its parts" is used to support the notion of holism. This point informs us that in complex and dynamic systems, separating out individual parts of the system for study may fail to recognize the larger and more significant patterns of behavior in the total system. This perspective is thus at odds with the dominant traditional scientific view which focuses on examining each particular element of the system under investigation. Thus we see in such traditional sciences as medicine a division of medical research and practice into multiple specialties segmented by the body part or subsystem under study. This traditional or reductionist view, breaking down systems into their smallest component parts, allows knowledge of micro level components, but fails to fit the pieces of the whole system into a coherent picture.

The concept of holism provides considerable insight as to why interdisciplinary approaches to the study of the implications of complexity are essential. For example, can we hope to understand human psychology simply through the reductionist study of the neuronal connections in the brain? And can we hope to understand politics simply by examining the behavior of political elites? A holistic approach to understanding the human implications of complexity thus entails the larger challenge of attempting to fit the many elements of psychology, culture, politics, and economics, and the implications of these seemingly diverse fields, into some coherent and understandable whole. While such practices may be viewed as peripheral to traditionalists, such holistic approaches form the basis of complexity studies and their implications for humanity and sustainable development. To separate humanity from nature and ignore the necessary interactions of the human/biosphere connection fails to recognize that changes in one part of the human/biosphere connection may create nonlinear interactions and thus unforeseen changes in other elements of these interacting forces (see also "complexity and sustainable development").

Yet, what are the sociocultural-evolutionary forces that have lead to these evolving social paradigms? The contemporary complexity sciences reveal that the same forces that drive evolving complexity in the natural realm also serve to expand the complexity of human social systems. In particular, the elements of openness, disequilibrium, and adaptive response allow the generation of the sociopolitical-economic and psychological forms of the "edge of chaos" that serve to create novelty and emergent behavior in sociocultural evolution. The entirety of these forces further serves to enhance the capacity of human social systems to develop as self-organizing systems.

Politico-economic complexity. At the time of this writing, 189 nations make up the Member States of the United Nations, with additional non-member states also in existence. This vast array shows tremendous variation in the degree and amount of complexity across these nation-states. The political configurations across this multitude of nations ranges from the advanced democracies to monarchies to military dictatorships. The world's national economies also show tremendous variety in structure and behavior. While the wealthiest nations live in relative luxury and employ many of the cultural aspects of post-industrial society, many of the people of the world's poorest nation's live in the same economic and technological circumstances as their ancestors have for hundreds of generations.

Increasingly though, complexity scientists see the elements of openness, disequilibrium, instability, and fluctuation as essential to the innovation and self-renewal necessary for the evolution of complexity in socio-political economic systems. These elements are seen as the backdrop for politico-economic systems that operate at the "edge of chaos" and are thus capable of adaptive responses to a variety of politico-economic challenges. Complexity scientists thus see open and dynamic human systems as the ones most capable of coping with modern complexity. We can thus view politico-socioeconomic systems as complex adaptive systems with the goal of developing adaptive responses to both internal and external problems.

The most relevant question concerning the challenges of politico-economic complexity concerns which mode of politico-economic organization is best prepared to handle these challenges (see also "Complexity, politics and public policy"). Knowledge from the complexity sciences appears to support democratic and open market-based economies as the systems most capable of handling modern complexity. While for some this conclusion may seem to be tainted by ideology, the continuing expansion of democratic polities and market-based economies throughout the world lends practical credence to this point. Moreover, insights from the complexity sciences suggest that democracy and market-based economies are essential to further enhancing the complexity of human social systems.

Extrapolating the adaptive and self-organizing elements of natural systems to human social systems reveals that the concepts of openness, instability, disequilibrium, and fluctuation are requisite for both producing and handling the dynamics of social change.

The free flow of information and communications and the freedom of self-expression serve as means for allowing democratic political systems to operate at the "edge of chaos." This ability provides politico-economic systems the capacity to generate novelty and innovations to create further complexity and new means for meeting societal challenges. At the core of these politico-economic systems is some relative degree of human freedom in the political and economic spheres. It is this freedom at the individual or local level that creates the potential for creative fluctuations capable of producing bifurcations that produce new means for responding to a rapidly changing world. Democratic polities and market-based economies however are messy, if not chaotic, systems. It appears though that this level of disorder engenders the instability required to innovate and change (see also "Complexity in socio-economic systems"). The relatively more democratic and market-based politico-economic systems have also created relative material abundance for their populations when compared with the more closed politico-economic nations. The openness to both their internal and external environments, with regard to the flow of information and technology, serves to provide democratic and market-based nations access to the innovations of other nations, creating a global network of continuous change and increasing complexity. The qualities of complexity embedded in more open political systems provide these polities the means for autopoetic responses to the challenges of increasing complexity.

Politico-socio-economic complexity can also no longer be limited to discussions of nation-states and national economies. The current global information network combined with the generally free flowing travel of goods and individuals has created a global economy and society that in many ways minimizes the focus on national boundaries. This has led to a transnational political arena that may expedite both international co-operation and the development of international criminal activity that is capable of using global systems to create large fluctuations with bifurcations and generate decreased complexity in the current politico-economic structure. Thus, there is a great potential for fluctuations to occur across the international political system. Antagonisms between nations have the potential to create nonlinear reactions that explode into global conflict. This possibility is further exacerbated by the potential for nuclear conflict in which even the survivors would not call themselves "winners." The larger global political challenge is thus to create interconnected systems in which all nation-states see themselves as mutually responsible for ensuring that conflict does not lead to bifurcations that either end human existence or throw humanity into a continuous downward spiral of decreasing complexity. Thus what is required is a "declaration of interdependence" acknowledging the linkages requisite for the survival and well-being of all humanity.

Socio-technical complexity. Modern complexity creates both significant opportunities and threats for the sociotechnical systems of the world. The technological infrastructure of the modern world is a vast science and information-based network of multiple interacting relationships and technologies. This vast network is both a response to and a result of increasing social complexity. Look back to the bifurcation diagram in Figure 1. Modern complexity clearly creates an increasing rate of social bifurcations in which periods of stability are increasingly short. Each innovation is rapidly replaced by more innovative technologies and possibilities. The pace of innovation creates emergent opportunities for solving human problems. The core technology of this emergent network is the computer–communications technology nexus some-times labeled "compunications." This network provides individuals, organizations, and nation-states the capacity to transmit and analyze massive amounts of data in milliseconds. The opportunities created by this compunications network range from the creation of a "global brain" that incorporates the totality of human knowledge to the development of an artificially intelligent, self-evolving global "infostructure" that takes humanity's knowledge-base and creates new modes of problem solving. The challenge for this emergent global paradigm is the creation of socio-technical structures that are capable of responding to increasing social fluctuations in which periods of stability are rapidly overtaken by new forms of socio-technical organization (see also "Complexity and organizations"). Individuals and organizations will be challenged to become complex adaptive systems capable of responding to the turbulence of change.

The socio-technical infrastructure of the post-industrial era also creates a threat. This threat concerns what scholars call the "limits of complexity." Historical analysis shows that as societies become more complex their capacity to handle increasing complexity is diminished, thus often eventuating in societal collapse. This raises the important question as to the point and extent to which the global compunications and international economic infrastructure can continue to sustain its own complexity. With increasing complexity, the costs of systems maintenance and of developing the human capital needed to maintain complexity become excessive. From an economic perspective, the problem of decreasing marginal returns arises in which expanding economic resources provide ever-smaller benefits under conditions of complexity. In short, large economic efforts provide increasingly small returns on investment. Furthermore, the inherent difficulties in developing organizational and institutional infrastructures become even more challenging as nation-states and the international system seek to develop coping mechanisms for modern complexity. Thus complex social systems while appearing resilient may actually be quite fragile. The challenge posed by the threat of complexity is thus to develop knowledge concerning the level of complexity that is manageable for societal maintenance and well-being.

Psychological complexity: The increasing politico-socioeconomic-technological complexity of the modern world places new stresses on the individual striving to cope with these emergent challenges (see also "*Coping with complexity and uncertainty*"). In an increasingly complex world of amazing variety and diversity, human beings must develop means to make sense of the intricacies of this world. The traditional means humans have used for handling such complexity is to simplify. Whether this effort to simplify is based on a fixation on religious tradition or on viewing the world as simply divided into "good versus evil," the drive to simplify our complex world raises questions about the capacity of humans to handle the depth of modern complexity. The limited capacity of humans to "objectify" their experience has also posed a difficult challenge. The powerful forces of cultural-political-economic systems make it difficult for humans to look at the world "outside of them-selves" and make a realistic and objective assessment of both their individual and their society's place and responsibilities in the world.

Complexity scientists have suggested that the psychological constructs necessary for living in a world of increasing complexity require that individuals "complexify" themselves. This notion of "complexify" means that individuals must develop psychological constructs that are adequately flexible to handle a world of increasing change. Fixated mental models in the face of increasing complexity will likely place individuals in a position of increasing frustration and despair.

Mihaly Csikszentmihalyi has suggested that the twenty-first century requires a new and holistic psychology founded on the notion of the "evolving self." If individuals are to cope with increasing complexity the notion of a fixed and static psychology is no longer adequate. Csikszentmihalyi notes that development of a complex psychology adequate for the twenty-first century requires increasing levels of both differentiation and integration. Differentiation refers to the extent to which an individual has many different "interests, abilities, and goals." Integration refers to the extent to which there is in the individual a "harmony that exists between various goals, and between thoughts, feeling, and action." The complex person is thus one with a dynamic set of interests and skills and the means to constantly adapt his or her emotions and actions to these changing interests and skills.

The psychology for coping with complexity requires constant assessment and reassessment with the acknowledgment that this process is akin to evolving complexity itself. In a world of increasing change, those who remain stable and fixed will suffer. Those individuals who revel in the dynamism that is life have the greatest potential for personal fulfillment and social contribution. This point emphasizes the value of the psychological construct of realization noted in Table 1. Rather than being subjected to the institutional requisites of industrial era esteem, individuals in the post-industrial complexity configuration may realize their potential outside of the confines of historical and institutional configurations.

6. Exploring Complexity: Agent-based Genetic and Emergent Models of Complex Systems

*"Any study which throws light upon the nature of "order" and "pattern" in the universe is surely nontrivial" (*Gregory Bateson).

Investigations into complex systems have created new challenges for the sciences. The traditional Newtonian assumptions of stability and linearity produced an array of statistical tools founded on producing predictable and stable results. The study of complex systems, however, in which nonlinearity, instability and change may dominate in natural and human systems, is not amenable to the static and mechanical analysis of most traditional statistical methods. Furthermore, as complex systems often defy prediction, this traditional scientific goal is of less value and concern when examining complex phenomena.

Developing methods for exploring complexity has posed a particular challenge for the social sciences. Throughout most of the twentieth century the social sciences attempted to emulate the methods of the natural sciences. These efforts were aimed at developing a "social physics" which, in an effort to emulate Newton's vision of a predictable and stable universe, would create predictable and stable knowledge about human affairs. Yet even given the increased methodological sophistication of the social sciences, social scientists have discovered that many of the problems of economics, politics, and social welfare continue to defy the best efforts of social scientific understanding. Many social scientists, however, came to realize at the end of the twentieth century that their efforts to develop a predictable social science were fundamentally misguided. This was due to the recognition that Newton's mechanics provided considerable understanding when investigating many of the rather simple and predictable systems of the natural world, but the human realm has never been as stable as the orbits of the planets or as the resulting reaction when the same combination of chemical compounds is mixed. Social scientists increasingly recognize that the social realm is inherently more complex than many of the simple systems of the natural world. This recognition has led to a re-energized social science that now understands that relying on simple mechanical and statistical methods for understanding the tremendous complexity of human behavior and human social groups simply will not work. Rather the search for qualitative patterns in complex social phenomena may better serve the goals of social science in a complex and unpredictable world.

This reality has led to the development of new sets of scientific tools for exploring complex systems (see also "Agent-based genetic and emergent computational models of complex systems"). Many of the new methods for understanding and exploring complex systems rely on the power of the modern computer to produce analyses, solutions, and simulations. These methods generally attempt to examine the dynamics of complex systems by exploring the nature and structure of patterns that complex phenomena produce over time. Computer-based analytical tools with unusual names such as genetic algorithms and neural networks are now employed by scientists to explore and find solutions to complex problems (see also "Genetic algorithms" and "Distributed artificial intelligence"). These methods are referred to as modes of "evolutionary computation," and they change and evolve in an effort to find the optimal solution to a variety of human and organizational problems. Genetic algorithms use a modular method of computer program development that allows some modules to extract information, as if genetically modifying their own computer code, from other program modules. Genetic algorithms thus "evolve" in an effort to find optimal solutions to complex problems ranging from organizational strategies to the design of telecommunications networks. Neural networks are premised on the neural networks that comprise the human brain. The aim of these computer programs is to develop programs that use algorithmic "connections" to build computer programs that learn.

Complex systems however present another challenge for analysts. The nonlinearity inherent in complex phenomena often defies exacting mathematical or computer-program based constructs. In short, while linear statistics are well developed, nonlinear mathematics are often quite intractable. This has led many complexity scientists to rely on graphical images to help them determine the relative complexity or the nature of change in complex systems. Thus a review of most books on the subject of complexity will present graphs and pictures of amazingly intricate pattern and diversity. Complexity researchers thus increasingly rely on examining the patterns in graphical images. Since the underlying mathematics of these images are not always conducive to mathematical exploration, the search for pattern dominates and graphical images supply the visual foundations of analysis. This visual foundation of analysis is seen as qualitative analysis, which is now a core element of complexity studies.

The most recent effort employed by scientists to explore complex systems is the expanded use of computer simulations. The simulation technique with the greatest promise for understanding complex systems is referred to as "agent-based modeling." Rather than focusing only on the mathematics generated by such models, agent-based models use the speed and graphic capabilities of computers to generate moving scenarios of simulated social situations on the computer monitor. Thus, agent-based modeling is another qualitative research technique aimed at providing visual images of the patterns created during the evolution of complex phenomena (see also "Exploratory simulation and modeling of complex social systems").

Agent-based models consist of two basic elements. These elements are "agents," which may represent individual humans or animals, and a "landscape" which serves as the environment in which agents interact and evolve. Agents are programmed to behave according to simple rules that determine how they will interact with other agents and how each agent will behave in its environment. These programmed rules can lead to nonlinear interactions both among agents and with their landscapes. Multiple agents with diverse "rules" can also be programmed to interact on the computer landscape. Agent-based models thus represent "artificial worlds" in which "artificial life" created in a computer is used to advance understanding of complex dynamics across a variety of fields and topics (see also "Artificial life and human societies"). Agent-based models in the social sciences have been used to simulate consumer behavior, traffic jams, and prison riots. A variety of software platforms now supports the development of such models.

Agent-based simulations for exploring complexity in human phenomena also employ a novel view of the creation and emergence of human social structures (see also "Memetic engineering and cultural evolution"). Agent-based modeling is based on the assumption that social structure and organization are created by the interactions of various agents on landscapes. This perspective varies from the conventional social science view that holds that social structure and organizations are primary to social interaction and are thus imposed on individuals from the top down. Instead, agent-based modeling assumes that structure and organization are created by the interactions of many individuals, rather than imposed on individuals through culture or institutional artifacts. Proponents of agent-based modeling thus see these simulations as "social science from the bottom up."

Agent-based modeling is seen as producing a "generative social science" because a goal of this perspective is to examine how social structure and organization at the macro level emerge from the micro-level interactions of multiple rule-based agents. The application of this approach has obvious implications for reconsidering social phenomena such as economic markets. Rather than assuming that markets are some mystical phenomenon imposed on agents by some "invisible hand," agent-based modeling assumes that markets are the emergent result, generated from the bottom up via the interactions of multiple individual agents on a landscape. The focus of these research efforts thus is to examine what emerges from the dynamics of human interaction. Agent-based modeling thus presents the hope to complexity researchers of devising a means for exploring the multiple possibilities that arise from human interactions across the vast array of human social interaction. While these simulations are not intended to produce singular solutions, agent-based modeling may come to serve as a guide to policy-makers as a means for appreciating the multiple outcomes that may emanate from human and governmental action.

7. Knowledge Management

"Knowledge is the only instrument of production that is not subject to diminishing returns" (J. M. Clark).

Knowledge: the intangible asset. Prior to the current dominant historical paradigm, the post-industrial paradigm, the physical assets of land and money were the dominant resources in human societies. The combination of the general evolution of complexity in the human realm and the current global sociotechnical-scientific infrastructure, however, serves to create a world in which knowledge and knowledge creation become the primary modes of social maintenance and adaptation. Knowledge is thus the driving force of the post-industrial paradigm (see also "*Knowledge management*"). Knowledge serves not only to create more complexity in the social realm but is also the primary means for handling the increasing complexity in our world. Thus, knowledge creation and production generate a self-reinforcing state of affairs in which the complexity created by increased knowledge requires even more knowledge to handle that complexity. Consider the evolution of the global Internet. As it has evolved, new knowledge must be constantly produced as the system expands and creates new forms of communication and commerce. Expanding and applying knowledge are thus essential to the continuous innovation required to sustain the networks of problem solving required by a world of increasing complexity.

Yet what is knowledge? To answer this question it is first necessary to sort out the many terms that are used as part of the knowledge infrastructure. One of these terms is "data" which refers to a raw statement of fact such as, "the temperature is 80 °F." Another important concept is the term information which places data in to some context, such as, "80 °F is quite warm in London for this time of year." From this perspective most contemporary computer systems referred to as "information systems" are actually "data systems" consisting of the movement of raw facts within and between computers. Placing the data in context, as in the production of a graph that shows how the data have changed, begins to give a relationship to the data and so creates information.

Knowledge is generally seen as including an action component, and thus comprises some active conclusion that can be derived from information. Thus information alone does not help to solve problems, for it is the active element of knowledge that generates its value in the current complex of human societies. Knowledge also comprises at least three other distinct components. One of these is the notion of tacit knowledge: the result of a person's experience and socialization that belongs specifically to that person. Tacit knowledge is a personal tool, owned by the individual, residing in his or her own mind, and is used to take action on any matter of current concern or focus. Knowledge is also based on rules. These rules concern the guidelines and filters individuals use from their experience and socialization to process information and generate active responses to information. Knowledge is also dynamic in the sense that it can change in response to experience and new circumstances. It can thus be seen as a dynamic and tacit resource based on rules that are used to act upon information (see also "Data, information, knowledge, and wisdom").

This definition of knowledge reveals an essential component of knowledge as an asset. Knowledge is an intangible asset. While it may seemingly be written down or placed in a computer database, genuine and actionable knowledge resides in the human brain (see "Theories of human cognition"). The concept of knowledge as an intangible asset also provides insight into the challenges of managing knowledge. The previous historical resources of land and money are tangible assets amenable to traditional methods of management and control. The post-industrial management challenge is to discover new means for managing the critical intangible asset of knowledge. Furthermore, we can begin to see that human cultural complexity appears to evolve from tangible critical social resources such as land and money to the intangible critical social resource of knowledge.

Knowledge as an asset also possesses unique characteristics relative to pre-existing dominant cultural resources. Unlike land and money, which have clear limits of supply, knowledge is an infinitely expandable and potentially unlimited resource. It is also a unique resource because once it is shared ownership becomes mutual. If one gives another person money, now only one person possesses that money. When knowledge is shared, both the provider and the recipient possess the resource.

Table 2 presents the essential managerial and organizational artifacts of the four periods of human cultural evolution. In the knowledge-based societies, analyzation becomes critical to the maintenance of socio-economic institutional stability and flexibility. Participative modes of leadership and organization come to dominate in post-industrial societies as the combination of intellectual power and a variety of diverse views enhances the capacity for managing evolving complexity.

Historical Eras

Dominant Managerial/ Organizational Artifacts	**Hunter-Gatherer**	**Agricultural**	**Industrial**	**Post-Industrial**
Management Stages	Dominance	Stewardship	Organization	Analyzation
Leadership Styles	Charismatic	Traditional	Rational/Legal	Participatory
Dominant Organizational Mode	Clan	Extended Family	Bureaucracy	Learning Organization
System Maintenance Requirement	Kinship	Caste	Mass Basic Education	Continuous Learning
Dominant Institutional Requirements	Survival	Stability	Incremental Adjustment	Rapid Flexible Response

Attitudes Toward Labor	Exploitation	Exploitation	Human Commodity	Human Capital

Table 2. Human Historical Eras and Managerial/Organizational Artifacts

Principles for managing knowledge. The total sum of knowledge retained by the employees of any organization or social institution can be seen as the "intellectual capital" of that body. Managing the intellectual capital of an organization requires new modes of thinking relative to the industrial modalities of managing hard assets such as physical plant, natural resources, or financial assets. These new modes of managing intellectual capital can now be operationalized by several basic principles that recognize the new challenges produced by managing an intangible asset.

One basic principle of knowledge management is that organizations do not own knowledge. They simply share ownership of knowledge with their employees. Since employees may simply "vote with their feet" and leave an organization at will, then organizational leaders must recognize that maintaining the knowledge and intellectual assets of their employees is a critical managerial function. In the wealthiest nations, organizations attempt to secure these intellectual assets with a variety of work benefits for employees aimed at both securing and expanding the organization's intellectual capital. Efforts to improve the quality of working life by providing employee benefits from health care to child-care represent one part of the variety of organizational efforts aimed at securing the knowledge resource. Efforts to expand organizations' intellectual capital range from financial subsidies for employees' continuing education to providing new and varied assignments as a means to produce new experiences for employees in order to develop their problem solving skills. Furthermore, in the knowledge organization, employees are seen as essential "human capital," rather than as an industrial age "human commodity" to be discarded when strategies change and when economic cycles reach a nadir.

Another principle of knowledge management concerns the application of teamwork and team-based organizations to the challenges of post-industrial socio-politico-economic complexity (see also "Knowledge management and co-operation technology"). In the industrial world an organizational knowledge elite could simply dictate to the great majority of employees what must be done, with the assumption that employees would accept these orders and abide by the defined mandate. This approach may function fairly well in stable environments. The speed of change and the concomitant turbulent organizational environments in the post-industrial era however require a broader use of the intellectual assets in organizations. One of the realities of post-industrial complexity is that no single person possesses the entire stock of knowledge requisite for problem solving. In a world of increasing complexity there is simply too much complexity for any single mind to be able to cope with it. For post-industrial organizations to respond to complexity requires that all employees be engaged in organizational problem solving. The industrial age tradition of hierarchical decision-making wanes under the tensions of rapid change. Teamwork among employees is now seen as a fundamental means for ensuring that multiple minds are involved in problem solving and decision-making. The assumption is that the dynamics of the application of the knowledge of multiple team members may produce nonlinear interactions that generate new forms of knowledge production and problem solving. Multiple minds are required to handle the multivariate complexities of post-industrial organizational reality. Furthermore, the application of multiple minds to problem solving is consistent with the interdisciplinary nature of the challenges of complexity (see also “The intelligent enterprise and knowledge management”).

Recognition of the importance of teams for knowledge creation and application also emphasizes the need for “communities of practice.” Such communities represent efforts both within and across organizational environments to bring together professionals with similar interests and responsibilities so that they can share their knowledge. These communities may engage in informal meetings, national professional conferences, or informal but organized discussions via e-mail lists that serve to use the “shared” quality of knowledge to expand the total base of knowledge within a profession. This principle further serves to emphasize the understanding that knowledge is a shared and intangible asset that crosses institutional boundaries. Knowledge tends to “leak,” thus proving that the apparent intellectual resources of one organization can easily be transferred to other organizations through communities of practice and the global information/knowledge network (see also “Information ecology and knowledge management”).

One of the aphorisms taught to most school age students is that “we only use a small portion of our total brainpower.” This aphorism holds true for traditional industrial age organizations. Most current organizations simply are not aware of the total base of knowledge held both by their employees and in the organizational stock of stored written communication. Without a means for identifying and using the stock of potential and relevant knowledge, organizations fail to capture and employ the entire body of knowledge capacity necessary for innovative response to turbulent markets and complex problems. This understanding has shown a need for organizational “knowledge audits” that aim to identify the stock of knowledge in an organization and relate this knowledge to organizational strategies and problem solving.

The knowledge audit is founded on several basic questions. First, organizational management must ask, “What are the critical knowledge functions of this organization?” This knowledge may be unique, given the unique missions of many market-based organizations, or it may be more generalizable, for example in areas such as basic governmental service functions. Defining the critical knowledge functions of an organization is a basic function in the administrative “analyzation” required in post-industrial organizations. Defining critical knowledge functions may also serve as an organizational guidance system that may alter organizational goals and strategies, and even redefine the organization as it seeks to secure an adaptive fit with its environment. A second question essential to the knowledge audit is, “Who possesses the knowledge required for the organization to survive and thrive?” This question demands that organizational leaders identify individuals within and outside the organization who possess the knowledge requisite for organizational success. One element of this task is the creation of a “knowledge inventory” that identifies the stock of knowledge assets that each employee possesses. This database of employee knowledge may then serve as a means to assign employees to a variety of tasks based on the knowledge they possess rather than on some predefined and static “job” with the organizational hierarchy. The identification of “knowledge gaps” can lead to a demand for new intellectual resources in the organization or the use of outside knowledge providers to expand organizational fitness. Even more significant is the understanding that, since knowledge is a dynamic resource, then knowledge inventories must be dynamic and change as employees obtain new knowledge.

A third critical question for the knowledge audit concerns how management can develop policies for both knowledge sharing and the management of organizational knowledge. Industrial era organizations are typified by “information islands” in which either employees guard information as a means of protecting some privileged position or that information is seen as only a unit level resource and not an organization-wide one. In the knowledge-based organization, knowledge is seen as an organization-wide resource that needs to be shared and disseminated widely (see also “The role of culture in knowledge management”). This requires that organizational policies be produced that both identify the source of new and existing knowledge and ensure that knowledge assets are available for constant access to all organizational employees. While traditional industrial organizations may rely on information and knowledge flow as based on a “need to know” basis, post-industrial organizations must employ the intellectual capital and creativity of all employees for adaptive response to complex problems. Another element of the management of knowledge concerns the handling of proprietary knowledge. While proprietary knowledge is used by both economic and political institutions as a means of competitive advantage, it also has “time-value,” which means that the value of that knowledge fades over time as the world changes. Thus the dynamic elements of knowledge management require vigilance to properly handle both the present and future value of knowledge.

A final question in the knowledge audit concerns how tacit knowledge can be turned into explicit knowledge (see also “Organizational knowledge creation and management”). Since tacit knowledge resides in the minds of people, this issue concerns how organizations can take what employees know and make that explicit, documented and transferable. This means that rather than producing information bases, post-industrial organizations must also cope with the complexity of creating knowledge bases. An optimal knowledge base would include the entire body of knowledge of all employees in a computer-based format that would allow access to any employee, from any location. While for most contemporary organizations this will take considerable time and effort, some business organizations are moving in this direction. The global corporation Ford Motor Company now has many of its experienced expert employees produce computer-based expert systems prior to their retirement. This computer software embeds their knowledge in the software and also allows current employees to query the knowledge base. This approach means that knowledge does not have to be lost as employees change careers or leave an industry. Thus, the future challenge is to develop improved means for developing such expert systems to ensure that knowledge is retained. A secondary value of this approach is in the area of knowledge transfer as the costs of knowledge production are mitigated by making pre-existing knowledge more readily available.

Organizing for knowledge management: continuous innovation. Industrial age bureaucracies are generally organized by function. In conventional business organizations, functions such as engineering, production, and marketing are separated into distinct units. This method of organizing however creates barriers between functional units in which each unit sees its own function as primary, thus diminishing the perceived need to share knowledge with the others. Thus rather than expediting knowledge transfer the traditional organizational configuration inhibits knowledge transfer across functional areas.

Knowledge based organizations require a novel approach to organizational structure and management. Rather than breaking problems down in the reductionist approach of the industrial era organization, knowledge based organizations view problems as premised on knowledge requirements that may cross functional organizational lines. The knowledge organization requires a more fluid approach to organizational structure than traditional organizations. Instead of using the competencies of employees in singular and consistent organizational activities, knowledge based organizations use the variety of employee knowledge and competencies to create a match between the problem at hand and the skills and knowledge required to solve it. Thus the traditional notion of a static job on the organizational chart is no longer meaningful. In knowledge organizations the knowledge goes to where the problem resides.

Scholars view the approach to organizing in knowledge organizations as operating “around process rather than structure.” The process of identifying the people with intellectual capital and the appropriate knowledge assets is just one part of a larger process of creating the fluid movement of relevant problem solving skills to the existing problem. The result of this approach is that employees are no longer limited in their work by their job descriptions. Instead they move from project to project depending on their knowledge of the varying challenges the organization faces.

Traditional hierarchy is limited in the knowledge organization. Hierarchy inhibits knowledge flow by creating a chain of command that slows communication and distances leaders from organizational challenges. Organizing around emergent challenges means that both the nature of work and work assignments are in constant flux. An individual’s position on the organizational hierarchy is also less meaningful in the knowledge organization. Individuals in the knowledge organization are valued for their knowledge and problem solving competencies rather than for their location on the hierarchical organizational chart. Flexible networks of knowledge designed to handle new complexities thus typify the patterns found in the knowledge organization. Knowledge is thus a “democratizing” influence. If what is valued is knowledge, then in the knowledge organization, the ultimate source of that knowledge, the individual, becomes the greatest asset.

8. Organizational Learning And Change

“*Live each day as if it were your last – and learn as if you will live forever*” (Mahatma Gandhi).

The demand for learning. The realization of the need for the management of knowledge, as a critical institutional requirement in our increasingly complex world, emphasizes a fundamental mismatch between the need for institutional change and the continued dominance of traditional bureaucracy. The organizations of the industrial period, which can be seen metaphorically as Newtonian machines, emphasize stability and predictability. This emphasis on stability and predictability creates industrial organizations premised on notions of management control. The task of the manager in these settings is thus to control people and processes in the hopes of producing predictability. Control however can be seen as a means of damping organizational dynamics that inhibit adaptive response.

Traditional industrial bureaucracy is also premised on notions of routinization and the specialization of work. Both of these elements inhibit human creative response. Following the same routine work day after day limits people's potential for personal growth and realization, as does specialization that asks people to focus on only a few things of perceived institutional importance. While traditional bureaucracy is well suited to stable environments, the instability and rapid change of modern complexity make industrial age organizations an apparent relic of the past (see "Organizational learning and change").

The cultural artifacts, the modes of living and the desires of many people in the most complex societies, require a post-industrial institutional response. Yet as much of the world moves toward post-industrialism, most of the world's organizations and institutions remain in an industrial mode. It is this mismatch between the requirements of industrial organizations and the contemporary demand for knowledge that is at the heart of this institutional disconnection. The post-industrial creation of knowledge in organizations however places new demands on organizations and people. The expanding appreciation for the new institutional requirements of complexity have produced the recognition that we need adaptive organizations capable of responding in creative ways to the challenges of increasing complexity. Scholars have thus begun to see organizations as complex adaptive systems that must respond to a rapidly changing world for their survival and maintenance. While many different post-industrial organizational types have been suggested, they all converge around the notion of learning. The result is a congruence of opinion that current and future organizations, whether governmental, business, or not-for-profit, must become "learning organizations" (see also "Public non-profit partnerships for social capital"). Learning thus becomes a key to knowledge production. Furthermore, learning becomes the key organizational variable that allows adaptive response and the capacity to produce positive fluctuations leading to organizational change to new levels of complexity and adaptive fit. Learning may thus generate the instability in organizations necessary for them to function at the "the edge of chaos" and produce innovative responses to the challenges of complexity. Look back to the bifurcation diagram in Figure 1. Learning can be seen as the primary resource that expedites the capability of organizations to respond to the increasing bifurcations in a complex world and adjust to the increasingly short periods of stability as complexity evolves.

Types of organizational learning. The concept of a learning organization raises the question as to what is meant by the term "learning." While scholars have developed various definitions of the concept, they all contain as a core the notion of behavioral change. In short, to have learned is to change one's way of behaving. This means that simply possessing knowledge does not mean that one has learned. The possession of knowledge only has value if individuals use this knowledge to change their behaviors in an adaptive way. Knowledge thus serves as a basis for learning but does not alone ensure learning. Knowledge reveals its power only when it is "enacted" and results in new behavioral regimes for the individual that provide new means of creative response. Thus there is an intimate connection between knowledge management and organizational learning. Knowledge must be produced and managed but continuous learning is essential for the handling of increasing complexity.

Scholars also recognize that several types of human learning occur within organizational environments. These types of learning are based on the amount and nature of learning that occurs. It is also necessary to understand that "organizations" represent groups of people directed at achieving defined goals. Thus it must be understood that individuals learn, and learning organizations produce and tap their learning. Management scholar Chris Argyris has defined three distinct types of learning that can occur in human organizations. These three are based on the concept of learning as a circular and iterative process that can either sustain existing modes of working and functioning or lead to novel forms of resolving organizational problems and new modes of working. The simplest type of organizational learning has been labeled "single-loop learning." Single-loop learning refers to incremental changes made within the existing framework of mental models used in an organization. Thus, single-loop learning occurs when organizational actors make small changes to their existing ways of behaving and responding but do not alter their basic vision of the organization and its tasks. This type of learning is typical of the incremental approach to change represented by the industrial era. Rather than allowing symmetry breaks within the existing organizational paradigm, single-loop learning confirms existing organizational functioning by requiring only small changes.

A second form of learning, within the hierarchy of organizational learning, is "double-loop learning." This form of learning serves to create transformative change in which completely new ways of behaving are achieved. This transformation stems from organizational actors testing pre-existing ways of functioning and performing work. The testing of pre-existing forms of organizational functioning often undermines the previous organizational model because new behaviors are seen as more adaptive and more responsive to rapidly changing socio-politicoeconomic complexity.

The highest state of organizational learning is referred to as "triple-loop learning" in which organizational actors "learn about learning." In triple-loop learning employees and managers become self-conscious about learning. This means that rather than simply adjusting their behavior or testing pre-existing modes of organizational functioning, organizational actors become explicitly aware of how they learn and the processes necessary to produce further learning. Triple-loop learning is thus a key element in creating learning organizations. Organizational employees not only understand how they learn and re-shape their own means of behaving, but are also capable of developing organizational structures and processes that expedite learning. Thus learning becomes the key goal of the triple-loop learning organization. While such organizations may have defined missions to provide services or goods, they see their more fundamental task as providing an environment in which employees learn and develop as professionals. This task is an essential ingredient in post-industrial organizations. In an era of turbulent change, in which organizational missions and strategies may change rapidly, expediting "learning about learning" is essential to developing intellectual capital.

Triple-loop learning thus expresses three critical elements of post-industrial management as shown in Table 2. First, analyzation is required to develop structures and processes for expediting learning. Second, learning enhances the capacity to respond in flexible ways to rapid changes in markets, and customer or citizen demands. Finally, means for developing continuous learning are essential to coping with the increasing bifurcations and symmetry breaks occurring in contemporary organizational environments. This point also expresses the need for "life-long learning" in which all citizens are engaged in a process of developing their intellectual capital on a continuous basis. The human capital requirements of modern complexity dictate the need for both organizational and societal structures that enhance the learning capacity of all citizens. A primary requirement then of post-industrial organizations is also to develop means for "organizational unlearning" (see also "The nature of organizational unlearning"). Processes that help organizational actors must necessarily replace the less adaptive and constrained modes of industrial era bureaucracy, and must help citizens develop means for shedding outdated ways of behaving and designing novel means for coping with complexity.

Systems thinking and organizational learning. Another major element of contemporary conceptions of the learning organization is the notion of "systems thinking." Systems thinking is premised on a critique of traditional industrial era organizations. This critique expresses the concern that traditional organizations focused on structures and static views of change without proper recognition of the processes and change that occur in organizations. Systems thinking focuses on the notion that organizations are sets of inter-related parts. To genuinely understand an organization one must understand the intricacies of these interrelationships. For systems thinkers, "the whole is greater than the sum of the parts." Systems thinking thus further focuses on a holistic rather than a reductionist view of organizations. The reductionist view segments people into specific functions and limits their capacity to think across functional boundaries. The systems view argues that organizational learning is expedited by creating environments in which employees consider the many linkages between their functions and the improved functioning of the entire organization. This approach enhances the free flow of information and knowledge across organizational units while enforcing the notion that all employees have an obligation to the improvement of the entire organization. Structure gives way to process in an effort to develop organizational processes and relationships that enhance learning and thus new modes of behaving.

A leading scholar in the systems thinking field is Peter Senge who has defined four other critical elements of the learning organization. These elements are personal mastery, mental models, shared vision, and team building. Personal mastery involves developing the capacities of "continually clarifying and deepening our personal vision, of focusing our energies, of developing patience, and of seeing reality objectively." Senge sees personal mastery as essential to developing the spiritual foundation of the learning organization. The concept of the spiritual foundation of the learning organization refers to the belief that genuine learning organizations must appeal to more than just the economic needs of people. Industrial organizations view people as *homo economicus* for whom work is simply a means of achieving an income. The learning organization however aims to develop the entire person beyond mere economic needs. This development must incorporate the total human being with all of the person's intellectual and spiritual assets. Thus the learning organization strives to tap all of the assets that people bring to the work place. Work is no longer just about getting a job done, but is seen as a complete experience for people, allowing them to use the totality of their intellectual, spiritual, and ethical resources. Thus while industrial era organizations "judged" people's performance, the learning organization intends to "develop" the full capacity of all organizational actors (see also "Organizational learning in the developing world").

The concept of mental models as an element of organizational learning concerns the deep assumptions that people hold about work and their organizations. The goal for learning organizations here is to allow people to question both their own mental models and the mental models that dominate their organizations. This means that people are asked to "discuss the undiscussable" and to question deeply held assumptions typical of double and triple-loop learning. The notion of a shared vision in learning organizations involves the managerial concept of "alignment" which refers to ensuring that all employees are properly informed and guided by the strategic vision of the organization. Without the congruence of shared vision, organizations tend to drift and lose the opportunity for rapid adaptive responses to post-industrial change. Thus, in the learning organization people are provided with the dual challenge of both questioning existing mental models and developing shared visions of organizational success.

The final element of the systems thinking model of organizational learning is team building. If team building is essential to successful knowledge management, it is an even greater imperative in the learning organization. Increasing complexity within the knowledge, technical, and external environment of organizations necessitates the capacity for moving within and across organizational boundaries. The aforementioned requirement for systems thinking also demands that employees with multiple interests must be involved in the process of organizational problem discovery and solution. Teams are thus a requirement of post-industrial complex adaptive organizations. Such teams however are not stable entities but rather shifting groups of individuals focused on the specific learning requirements and competencies produced by each new challenge for the organization.

The self-organizing learning organization. Hierarchy and the mechanisms of control typical of industrial bureaucracies create unit level and individual behavioral regimes resistant to change. Specialization, efforts to create predictability, and excessive emphasis on organizational structure inhibit the potential for industrial era organizations to respond to rapid change. Thus such organizations are challenged to handle even the incremental adjustment requisite for the occasional fluctuations that disturb them. The demands of post-industrial learning organizations, however, require rapid and flexible responses to constantly emerging challenges. This means that learning organizations must function at the edge of chaos and develop means for self-organization without the mechanisms of management control typical of industrial era organizations.

A critical task for the learning organization is to develop and use a comprehensive set of strategies and processes that expedite the capacity of the organization and its members to rapidly "self-organize" in response to environmental fluctuations (see also "Reciprocity: a keystone of organizational learning"). The learning organization thus must both generate and respond to symmetry breaking events, allowing it to develop rapid and adaptive responses to its environment. Whether fluctuations in the learning organization are internal changes produced by the demands of new methods and practices or external fluctuations generated by changes in markets or missions, these organizations find novel means for responding to the continuous novelty of post-industrial turbulent change. Functioning at the edge of chaos also requires learning organizations to develop a total systems package for promoting adequate flexibility for survival. The elements of this total systems package include the testing of mental models and the creation of formalized structures for producing and managing continuous innovation. Employees must also be liberated from the confines of industrial age specialization of work and be allowed to use the totality of their intellectual resources to design new solutions (see also "Sustainable development of electronic teaching in universities").

A genuine learning organization is an autopoetic system. The processes of self-renewal that exist in all living systems must also exist in the learning organization. Without such processes, organizations may suffer the consequences of entropy, falling into the trap of outdated structures and responses to novel challenges. Only when dynamics are allowed to express themselves in organizations can organizations develop the means for self-renewal. The crushing consequences of excessive management control that limit freedom of thought and action also limit opportunities for self-renewal and adaptive response. Thus, in the learning organization management takes on a new role as "helper" and "servant" whose task is to provide workers with the tools, resources, and environment requisite to enhancing the use of the intellectual resources of all. The leader in the learning organization no longer sits atop the hierarchy, with the crushing weight of control and dominance, but rather acts through knowledge and the capacity to build organizational systems that enhance learning.

The learning organization must thus be capable of handling post-industrial uncertainty. Such uncertainty, however, is seen not as a threat but rather as an opportunity for symmetry breaking events that lead to continuous innovation and response. Contemporary management theorists describe the challenges of increasing complexity as requiring the ability to "thrive on chaos." This means that chaos and uncertainty are not seen as threats but rather as necessary conditions for self-organization and autopoetic processes to emerge and shape the new conditions for success.

Finally, such self-renewal must re-incorporate the fun and enjoyment of learning that human beings possess in their youth. The desire for rewards and learning that is only specifically task-oriented typifies the industrial organization. Industrial era adults learn to respond to extrinsic incentives in which learning is seen only as a means to some reward such as money or heightened esteem. Post-industrial complexity requires that "learning for the sake of learning" becomes an expanded value. Knowledge that may seem detached from typical organizational work may however enhance systems thinking by allowing workers to see the many intricate connections between working life and the challenges faced by their organizations. Work thus becomes in post-industrial society a means for the full realization of the individual. The fun and enjoyment of learning that humans experience in their youth is paramount to the design and development of the autopoetic learning organization.

9. Organizational Learning and Ecological Economics

"*Economics should remind itself that nature is the economy's "life support system." By ignoring this essential link we could threaten the ability of natural life support systems to maintain themselves and the economies to which they are inexorably linked*" (Robert Costanza and Herman Daly).

Organizational learning also has profound implications for the sustainability of planet earth. Ensuring a sustainable environment will require that a large proportion of business organizations learn new practices and modes of production consistent with maintaining the integrity of the natural environment. In the twentieth century, traditional economics focused only on the value added by the production of finished goods created from resources extracted from the natural environment. For traditional economics, the extraction of natural resources is seen as a cost only in the sense that there is an economic cost to extract those resources. The losses to the natural environment created by industrial era production and resource use are not seen as any larger cost to the planet. Yet, the increasing recognition of natural resource depletion and environmental degradation has generated a new view of economics that sees natural resource extraction and environmental degradation as fundamental economic costs that force a reconsideration of the very basis of economic thinking (see also "Economy as ecosystem").

This emergent view of economics is now labeled ecological economics. Ecological economics sees the natural environment as the basic economic resource of the planet. If this basic economic resource is depleted or degraded the costs to all of humanity are high. Ecological economists see the use of non-renewable natural resources as a "cost to the planet." This view thus requires a reconsideration of the primary notions of economic value and profit. While a corporation may profit from its extractive efforts and goods production, the planet loses value due to the loss of its sustaining forces and potentially to its integrity to maintain the processes of self-renewal. Thus, if losses to the planet are factored in to corporate "profits" it may be that few extractive industries are actually creating profits. Instead the extractive economics of industrial era business organization are creating long-term losses for the planet (see also "Economic growth and sustainable development").

One response to the growing recognition of the insights of ecological economics is the concept of "natural capitalism." Natural capitalism argues that the production of goods and services within the model of capitalist development must incorporate the sustainability of the earth's natural resources as a primary goal of economic development. This view maintains the basic premises of capital accumulation and free markets as basic to human development, but demands that these accumulative processes and markets incorporate a fundamental respect for natural resources and environmental quality. The recommendations of natural capitalism range from environmentally friendly automobiles to the production of naturally degradable products only. Other efforts within this emerging paradigm include the recommendation that consumers be allowed only to lease durable consumer goods such as automobiles and refrigerators from the original manufacturers. The manufacturers would then be required to ensure that large portions of these manufactured goods were either biodegradable or amenable to "re-production" to create incentives to minimize resource depletion and the environmental degradation that accrues from the "throw-away" society that typifies the industrial era.

Considerable learning will be required for ecological economics and natural capitalism to take hold in the *Weltanschauungen* of the leaders of many industrial era manufacturing organizations (see also "Ecological systems and multi-tier human organizations"). This understanding reinforces the importance of systems thinking as a basis for organizational learning. Industrial organizations must be awakened to the reality that their behavior has an impact on the larger global ecological system. All of humanity is a part of this larger system. And in a nonlinear world, in which, "we cannot do just one thing," and in which it is impossible to predict the outcomes of the interactions in complex systems such as the global ecosystem, new modes of organizational learning are essential. The behavioral changes required by ecological economics are great, but these changes in institutions are essential to the sustainability of the planet. There is an essential need for new creative means of economic production that maintain the integrity of the ecosystem while developing and designing institutional modalities that recognize and support the notion that the earth itself is our primary economic resource. Perhaps, the depth of the challenge presented by and for ecological economics is best made by Peter Allen who noted, "the idea [sustainable development]) should not be interpreted as the search for the perfect equilibrium. The world will never stop changing, and what sustainability is really about is the capacity to respond, to adjust and to invent new activities. The power to do this lies not in extreme efficiency, nor can it be had necessarily by allowing free markets to operate unhindered. It lies in creativity."

10. From Knowledge to Wisdom in Human Evolution

"*But ultimately we are called upon to develop an ethics which I should like to call an evolutionary ethics. It would not only transcend the individual but all of mankind, and explicitly include the main principles of evolution, openness, non-equilibrium, the positive role of fluctuations, engagement and non-attachment. Here, at the start of a worldwide creative crisis which puts the traditional ways of our life in question at all levels, we are still far from formulating and implementing such an evolutionary ethics*" (Erich Jantsch).

Sustainability of the earth's life support systems and knowledge management: the knowledge foundations of an evolutionary ethic. To develop the evolutionary ethic noted by Erich Jantsch above will require the comprehensive management of humanity's knowledge resources. In particular the management of humanity's knowledge of environmental degradation and the knowledge of the earth's mechanisms of autopoetic renewal are essential for the promotion of global sustainability. While this base of knowledge is generally well understood by the scientific classes, most of the world's inhabitants are not aware of the intricate balances and linkages between individual behavior and global environmental damage. Furthermore, humanity must begin to move beyond the mere use of knowledge to the application of wisdom. But what is wisdom, and how can it be employed to ensure the sustainability of the planet?

Wisdom can be defined as "knowledge of the consequences of our actions," or as "knowledge of what is genuinely important." Both of these definitions have clear saliency for the sustainability of the planet. Wisdom as the "knowledge of consequences" speaks to an appreciation for the inherent nonlinearity of the world. In this sense, wisdom must also recognize the tendency for "unanticipated consequences" in a dynamic world filled with fluctuations and the potential for symmetry breaking events. Wise action concerning sustainability must accept that complexity limits our capacity to understand all possible outcomes of human action. Thus an essential understanding of knowledge of consequences is, as noted by Peter Allen, "knowing that we cannot know is an important step on the road to wisdom." In a non-linear and complex world even our best efforts to predict the downstream consequences of our actions are bound to fail. Thus wisdom also requires humility. A humility based on the understanding that human knowledge is limited and bounded by experience, training, and socialization requires the recognition that careful action is required in both environmental and global political systems whose fluctuations may defy our seemingly wisest efforts.

Wisdom as knowledge of what is genuinely important also speaks to the challenges of sustainability. This notion of wisdom leads directly to the values of post-industrial society. The concept of realization includes not only the fulfillment of one's unique psychological needs but relates also to the spiritual needs of each human. The fulfillment of these higher level spiritual needs is the direct link to defining what is genuinely important in life. Philosophers have known for centuries that the spiritual life is necessary for the full development of the human being. However, the industrial era's focus on constructs based on hierarchy and dominance inhibit and defy wisdom. Post-industrial wisdom requires that realization become a goal for all. Knowledge of what is genuinely important also distinguishes between what is in the "self-interest" of the individual and what defines the "enlightened self-interest" of all. The concept of enlightened self-interest is essential to developing wisdom about the sustainability of the earth's life support systems. Enlightened self-interest tells us that it is in the interest of all of the inhabitants of the planet to ensure that our only planetary home is maintained not only for ourselves but also for future generations. Short-term self-interest may serve the individual but degrade the global environment. Thus enlightened self-interest, knowledge of what is truly important, is essential to the development of an evolutionary ethics.

Knowledge management also requires a consideration of what human beings actually know about the current status of the earth's ecological systems. One critical element of this knowledge base is the relative usage of material resources among the nation-states of the global political system. The material abundance of the wealthiest nation-states of the world creates fundamental problems for the sustainability of the planet. The reliance of these economies on a variety of natural resources, with the ensuing degradation of the earth's environment, suggests that while these politico-economic systems represent tremendous improvements in human freedom and human material conditions, they also threaten the planet's carrying capacity.

At present, the dominant democratic market-based nation is the United States, which comprises a mere 4 percent of the world's population, but uses approximately 30 percent of the world's extracted natural resources. Scientists have developed a measure of resource usage for each of the world's nation-states. This measure is referred to as the "ecological foot-print" and defines the number of land hectares required to maintain the lifestyle of each citizen in each nation-state. Citizens in the United States of America each require 10.3 hectares of land usage and resource extraction to support their lives. This statistic contrasts markedly with citizens in the poorest nations such as Bangladesh in which the ecological footprint of each citizen is 0.5 hectares.

Thus the ecological footprint as a measure of the gap between the rich and the poor raises dire questions about the planet's sustainability if the dominant Western model of economic growth is to be employed throughout the planet. Recent estimates indicate that for all of the earth's current inhabitants to use the same level of natural resources as do citizens of the United States would require an additional five planet earths to support all of the current earth's inhabitants. Rapid economic growth in nations such as the People's Republic of China, with its more than 1.2 billion citizens, emphasizes the immediate threat to the earth's carrying capacity.

At the core of this global threat is an evolutionary problem. The evolutionary past of *Homo sapiens* (the wise man) built in deep competitive elements as a means to survive in a harsh world. This basic biological drive for competition has however been extended into the social realm, as not only individuals but also nation-states compete for access to power and resources. In the Western world competition is heralded as the key to national wealth and the growth of adaptive organizations capable of responding to the multivariate challenges of both industrial and post-industrial societies. Yet competition alone does not make for successful economies and societies (see also "*Mutualism and co-operation*"). Complexity researchers increasingly see the value of co-operation to the maintenance of successful economies. A closer look at the complexity of economic and social systems behavior shows, as Peter Allen notes, that "the history of a successful society within a region, is largely a tale of increasing cooperation and complementarity, not competition."

The narrow view of competition is also evidenced in the Western notion that "markets" are the solution for many of humanity's problems. The wisdom of complexity teaches us however that, in a complex world, singular solutions are unlikely to match the complexity of the world. This point is expressed more gracefully by Peter Allen:

The idea that we can solve our problems by simply releasing the forces of the "free market" is an illusion. The real complexity of the world involves the fact of collective structure, which is not amenable to any simplistic solution, be it central planning or free markets. The goals and strategies, the ethics and understanding of individuals fashion the collective structure that emerges, and give it complex properties, which act on each individual uniquely, and which cannot easily be resumed in a few criteria.

Thus multifaceted solutions are necessary in a multivariate and dynamic world.

Students of sustainability have proposed policies that reflect efforts to incorporate wisdom into environmental action and policy. The international "Next Step" organization has developed four principles aimed at producing a sustainable global society. These four principles are based on scientific principles that state:
In a sustainable society, nature is not subject to systematically increasing: 1. concentrations of substances extracted from the earth's crust; 2. concentrations of substances produced by society; 3.degradation by physical means; and, in that society…. 4. human needs are met worldwide.

The wisdom of these four principles reflects a fundamental wisdom involving the definition of what is genuinely important in life.

The four principles identified by the Natural Step organization serve as one foundation of the "evolutionary ethic" noted by Jantsch in the epigraph quoted earlier. A degraded planet, no longer able to support human life, serves the interest of no individual, group, or nation. Thus, wisdom informs humanity that what is genuinely important is the maintenance of life on the planet. Enlightened self-interest calls for careful attention to the life support systems of the planet. An evolutionary ethic must first serve to ensure the habitability of the planet. Without this ethic, the home of all humanity is at risk.

Sustainability of the earth's life support systems: lessons from the complexity sciences. One of the fundamental principles emerging from the sciences of complexity is the inherent uncertainty of our nonlinear world. This uncertainty is increased when considering highly complex and interdependent systems such as the earth's ecology. Uncertainty accrues however not just from the number of components in a complex system but moreover by the number of interactions between the components in that system. It is this potential for vast and unanticipated interactions that make the management of complex systems such a forbidding task. In simple systems, cause and effect can be tracked and calculated. In complex systems tracking cause and effect is extremely daunting and generally incalculable.

Students of the sciences of complexity often note that when contending with complex systems "you cannot do just one thing." This means that the interactions of many elements in the complex system may create interactions, effects, and outcomes that simply defy any human capacity for prediction. This knowledge has direct implications for the sustainability of planetary resources. The extraction of natural resources so necessary for industrial society, with its concomitant dissemination of those extracted materials back into the atmosphere, may generate changes that are yet to be seen or projected. Thus, once again, our ignorance of complex systems requires careful considerations of our actions.

Recently scientists have developed a framework for dealing with conditions of high uncertainty typical of complex systems. This framework is called the "precautionary principle," and concerns those situations in which scientific knowledge is limited or uncertain and in which there exists a potential for harm to individuals or groups.

Uncertainty in this case may refer to scientific ignorance, the indeterminacy of large systems, or the uncertainty of the proper parameters for building scientific models. These elements of uncertainty are directly correlated with our ignorance of and the indeterminacy of complex systems. The suspected harm identified in the precautionary principle concerns potential threats that cover large areas, that may extend over long time periods, and whose results are irreversible and cumulative. Again, the harms noted in the precautionary principle are also correlated with what is known about the nature of unanticipated outcomes typical of action in complex systems. Complex systems are generally irreversible, problems tend to be cumulative, and may become serious if not properly and continuously monitored.

The combination of scientific uncertainty and suspected harm that constitutes the precautionary principle results in what scientists define as precautionary action. Such precautionary action is premised on the two basic actions of prevention and anticipation. Thus precautionary action involving complex systems requires that preventive action occurs while efforts are also made to anticipate the outcomes of proposed and implemented solutions. The precautionary principle thus serves as an essential guide for the management of the earth's life support systems. Preventive action and anticipatory efforts must be made when considering the impact of globalized economic growth on the planet. The complexity of the ecosystem requires that precaution become an essential principle when considering the effects of human action on the environment.

The precautionary principle is particularly salient when considering that the self-organizing properties of our world do not have to result in positive outcomes. Pushing the planet's ecosystem into excessive states of disequilibrium may result in instability in the natural environment that results in outcomes detrimental to all human beings. This point displays a fundamental challenge concerning sustainability and complexity. Because it is not possible to be confident of the effects of human action in large-scale systems such as the earth's environment, humanity must take precautions to prevent and anticipate activities that may, even potentially, destabilize the planet's environment.

The precautionary principle thus provides further insights into the nature of an evolutionary ethic. When working with complex systems, caution must be a basic concern. This caution is especially important given that human beings are the only animals to actually control their own evolution. This knowledge thus requires that to control our own evolution demands careful attention to our species' basic resource, the planet earth. Wisdom concerning the autopoetic properties of the planet requires that humans appreciate that they have the means to undo this elemental quality of living systems.

Sustainability of Life Support Systems: Lessons from Organizational Learning. Learning is at the core of Jantsch's call for an evolutionary ethics. The institutions of the industrial era socio-economic structure rely on the extraction and thus the depletion of much of the planet's natural resources. These institutions must "learn" to implement an ethic of sustainability based on the awareness that enlightened self-interest demands greater concern for the life support systems of the planet that all humans call home. Since learning requires behavioral change, these institutions must engage in the challenging process of changing behaviors related to the extraction of natural resources and the production of goods that decompose in manners consistent with environmental integrity. The learning embedded and espoused in the field of ecological economics typifies the nature of this learning challenge. Major economic institutions and structures, including the scientific study of economics, must rethink their basic assumptions about the environment and economic development to ensure the sustainability of the earth's life support systems. What is needed at this point in human history is triple-loop learning within all human institutions.

Consider the institutional learning required on a global scale for the implementation of the Natural Step program noted above. The first principle of the Natural Step is directed at limiting the systematic increase in the "concentrations of substances extracted from the earth's crust." This mandate would require that the global reliance on fossil fuels be completely redirected to more sustainable and renewable energy resources. The second principle of the Natural Step, devoted to limiting "concentrations of substances produced by society," requires a complete change in behavior concerning the design of production methods and consumer goods that degrade the atmosphere and require increasing land use for waste storage. The third principle, of limiting the "degradation by physical means" of the earth's resources and natural environment, also requires radical changes in behavior for the vast majority of the economic institutions on the planet.

The industrial era was premised on the creation of stable organizations capable of maintaining order and some basic level of material comfort for large masses of the citizenry of industrial era nations. The stability of these organizations is now, in part, maintained by the vested interests of those whose short-term self-interest is at odds with the longer-term enlightened self-interest of all humans. The changes in institutional behavior and individual behavior required thus to produce an evolutionary ethic are large changes requiring learning at all levels of human organizational hierarchies. The task of post-industrial sustainability is thus to provide the knowledge of an "environmental ethic" that is followed by the learning required to create an ecological "declaration of interdependence" in which all economic actors maintain both an awareness and a body of actions necessary for the maintenance and support of the earth's life support systems. This need for institutional change is elaborated by Mihaly Csikszentmihalyi:

A good society, one that encourages individuals to realize their potential and permits complexity to evolve, is one that provides room for growth. Its task is not to build the best institutions, create the most compelling beliefs, for to do so would succumb to an illusion. Institutions and beliefs age rapidly; they serve our needs for a while, but soon begin to act as brakes on progress…. The task of a good society is not to enshrine the creative solutions of the past into permanent institutions; it is, rather, to make it possible for creativity to keep asserting itself.

This quote shows the importance of knowledge management and organizational learning in our world. The aging structures of the industrial era are increasingly ill adapted to modern complexity. Yet, Csikszentmihalyi's point also speaks to the challenges of sustainability on our planet. The continued fragmentation of human thought and human societies into enclaves of self-importance reveals the challenges of "allowing creativity to keep asserting itself." The tendency for human beings to invest in modes of thinking that secure their own material comfort, but not that of the entire planet, may lead to consequences that serve the interests of no one.

Moving from knowledge to wisdom for human organizations thus means that wise action requires a reconsideration of humanity's role as the most influential life form on the planet. Just as humans are the result of the evolutionary process, so also they are an integral part of that process. Humans are the only animals with the capacity to change both their own evolution and the larger evolutionary processes on the planet. Thus humankind must also be the "ethical animal," capable of showing proper concern for the larger autopoetic processes essential to the self-renewal of the planet. Thus genuine wisdom, guided by learning, is essential to move to an evolutionary ethic that "would not only transcend the individual but all of mankind, and explicitly include the main principles of evolution, openness, non-equilibrium, the positive role of fluctuations, engagement and non-attachment" (Jantsch, 1980).

Incorporating the wisdom embedded in knowledge management, the sciences of complexity, and organizational learning requires that humanity instill the precautionary principle as a basic framework for handling the inherent complexity and uncertainty that imparts the autopoetic and self-organizing properties of our world. The precautionary principle is perhaps best reinforced by these comments by Nobel Laureate Ilya Prigogine and his colleague Isabelle Stengers:

We now know that societies are immensely complex systems involving a potentially enormous number of bifurcations exemplified by the variety of cultures that have evolved in the relatively short span of human history. We know that such systems are highly sensitive to fluctuations. This leads both to hope and threat: hope, since even small fluctuations may grow and change the overall structure. As a result, individual activity is not doomed to insignificance. On the other hand, this is also a threat, since in our universe the security of stable, permanent rules seems gone forever. We are living in a dangerous and uncertain world that inspires no blind confidence.

In a world of uncertainty, caution is required and our species must recognize that it alone has a responsibility to all generations to leave them an inhabitable planet. Only through the proper application of humanity's base of knowledge combined with the wisdom of enlightened self-interest can humanity develop the learning that is essential to the sustainability and responsibility required in a dynamic and complex world.

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Glossary

Agent-based modeling:	A computer-based modeling method in which individual "agents" simulating human or animal actors, with defined and varying behavioral rules, are placed on a landscape of interaction. These models attempt to explore complexity by examining what emerges from the interactions of the agents on the landscape.
Autopoesis:	A characteristic of living systems to continuously renew themselves and to maintain their structure through processes of self-regulation.
Bifurcation:	A branching or forking leading to a qualitative change in the behavior of a system.
Complexity:	The degree and extent of human ignorance about any known natural or human system.
Complex adaptive systems:	Complex systems that adapt yet maintain their fundamental coherence during the process of adaptation.
Complex system:	A system with interacting parts and nonlinear relationships that may generate emergent behavior and evidence self-organization.
Dynamics:	The processes, mechanisms, and nature of change.
Ecological economics:	An emerging and interdisciplinary science aimed at advancing the understanding of the inti-mate linkage between ecology and economics for the betterment of nature and humanity.
Edge of chaos:	A trait of complex systems in which a balance between order and chaos is maintained.
Emergence:	The creation of novel structure and behavior at the macro level created by the interaction of multiple particles or agents at the local level.
Fluctuation:	A disturbance to a system that may be generated internally or by some external force or agent.
Fractals:	From the Latin *fractua*, meaning irregular. Refers to the fact that nature is comprised of irregular shapes and forms.
Ecological footprint:	The varying number of acres or hectares required to sustain the life of one citizen. The ecological footprint varies greatly among nations since some nations use considerably more resources per person than do others.
Knowledge:	The capacity to act upon information. Knowledge is an intangible asset.
Knowledge audit:	The process of identifying and defining the knowledge in an organization required to complete specified projects.
Knowledge management:	The process of managing the intangible asset of knowledge.
Intellectual capital:	The total stock of knowledge an organization or an individual possesses.
Nonlinearity:	Relationships between variables in a system in which cause and effect may not be proportionate, often leading to small causes creating large effects.
Open systems:	Systems that take in energy from their environments and

distribute that energy back into the environment.

Order through fluctuation: The process in nature in which new forms of behavior and structure emerge as the result of a disturbance generated either internally or externally.

Organizational learning: The process by which organizational actors develop both new regimes of behaving and new responses to emerging organizational challenges.

Precautionary principle: Refers to those situations in which scientific knowledge is limited or uncertain and in which there exists a potential for harm to individuals or groups. The precautionary principle requires that the two basic precautionary actions of prevention and anticipation be implemented in such uncertain situations.

Sciences of complexity: A broad interdisciplinary science focusing on the structure, nature, and dynamics of complex systems.

Self-organization: The internally produced capacity of many natural systems to alter their pre-existing structures and behaviors during periods of instability and produce more adaptive and novel forms of structure and behavior.

Symmetry break: A qualitative change in the existing symmetry of a system's structure or behavior.

System: Any organized and interactive grouping of parts with some defined goal.

Systems theory: A school of thought that attempts to find common elements across all natural and human systems. Makes the general statement that all living systems require the three elements of input, processing, and output for survival.

Systems thinking: Thinking aimed at examining the dynamic interactions and change processes in known systems in an effort to solve problems.

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Biographical sketch

L. Douglas Kiel is Professor of Public Administration and Political Economy at the University of Texas at Dallas. Kiel's areas of expertise include the managerial and social implications of complexity and quality and productivity improvement. Professor Kiel's published works in the field of complexity are cited in more than 100 academic journals ranging across fields as diverse as public administration, policy studies, economics, and psychology. His book, *Managing Chaos and Complexity in Government: A New Paradigm for Change*, *Innovation and Organizational Renewal* (1994), received the 1994–5 best book award from the Public and Non-Profit Sector division of the Academy of Management. His 1993 Public Administration Review article, "Nonlinear Dynamical Analysis: Assessing Systems Concepts in a Government Agency," was reprinted in Shafritz and Ott's edited book, *Classics of Organization Theory* (1996). He has also edited two books, *Chaos Theory in the Social Sciences: Foundations and Applications* (University of Michigan, 1996) and *Nonlinear Dynamics, Complexity and Public Policy* (Nova Science, 2000). He is a co-editor of the Proceedings of the National Academy of Sciences entitled, *Adaptive Agents, Intelligence and Emergent Human Organization: Capturing Complexity Through Agent-Based Modeling* (2002). He has served as a management consultant to a variety of government and business organizations.