Complex adaptive systems: concept analysis

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Aim. The aim of this paper is to explicate the concept of complex adaptive systems through an analysis that provides a description, antecedents, consequences, and a model case from the nursing and health care literature.

Background. Life is more than atoms and molecules – it is patterns of organization. Complexity science is the latest generation of systems thinking that investigates patterns and has emerged from the exploration of the subatomic world and quantum physics. A key component of complexity science is the concept of complex adaptive systems, and active research is found in many disciplines – from biology to economics to health care. However, the research and literature related to these appealing topics have generated confusion. A thorough explication of complex adaptive systems is needed.

Methods. A modified application of the methods recommended by Walker and Avant for concept analysis was used.

Findings. A complex adaptive system is a collection of individual agents with freedom to act in ways that are not always totally predictable and whose actions are interconnected. Examples include a colony of termites, the financial market, and a surgical team. It is often referred to as chaos theory, but the two are not the same. Chaos theory is actually a subset of complexity science. Complexity science offers a powerful new approach – beyond merely looking at clinical processes and the skills of healthcare professionals.

Conclusion. The use of complex adaptive systems as a framework is increasing for a wide range of scientific applications, including nursing and healthcare management research. When nursing and other healthcare managers focus on increasing connections, diversity, and interactions they increase information flow and promote creative adaptation referred to as self-organization. Complexity science builds on the rich tradition in nursing that views patients and nursing care from a systems perspective.

Keywords: chaos, complex adaptive systems, complexity, nursing

Introduction

The question of what is life has plagued scientists and philosophers for centuries and was formulated by the ancient Greeks in terms of substance: What is life made of? What is its essence? The Greeks answered the question about substance in the sixth century with descriptions of the four fundamental elements: earth, air, fire, and water (Capra 1996). But the ancient Greeks also asked about form: How does life fit together? Form is ultimately a question of patterns. The question of substance leads one to focus on the pieces of the whole. The question of form leads one to focus on the whole. To answer the question about what is life, both substance and form must be considered. If we are concerned about the latter, that is, the question of form, then we ask not about individual parts, but about how the parts fit together in relationship to each other; we ask about patterns. A focus on patterns has resulted in considerable analysis and research that is often referred to as systems thinking. The value of systems thinking was expressed by Capra (1996, p. 81), physicist and philosopher:

> From the systems point of view, the understanding of life begins with the understanding of pattern…or the configuration of ordered relationships…what is destroyed when a living organism is dissected is its pattern…while it is true that all living organisms are ultimately made of atoms and molecules, they are not 'nothing but' atoms and molecules. There is something else to life, something non-material, irreducible – a pattern of organization.

From this emphasis on pattern, that is characteristic of systems theory, has come the most recent generation of conceptualizing and modelling of living systems that now is known as complexity theory, complexity science, or in mathematical terms, non-linear dynamics (Capra 2002).

The concepts and perspectives from complexity science cross many disciplines – from physics to biology to chemistry and, more recently, to the applied sciences of management and health care. A survey of dissertations published between 1979 and 2003 with the subjects of complexity science, complexity theory, or complex adaptive systems reveals 51 titles that range from the emergence of languages as complex adaptive systems to genetic algorithms for agent evolution (UMI Dissertation Express 2004). Indeed, there are many who believe the ideas and principles in complexity science also resonate with and have value for the human social systems as well as the physical sciences (Lewin 1999).

From the early 1990s to the present day, the nursing, medical, and business literature reflects the fact that complexity science is no longer limited to the sciences of biology, physics, and mathematics from which it sprang (Stacey 1992, 1996, Plsek & Greenhalgh 2001, Anderson & McDaniel 2002, Haigh 2002, Anderson *et al.* 2003, Porter-O'Grady & Malloch 2003). Although there certainly is applicability of the concepts from complexity science to health care, greater clarity and precision is needed as the field develops so that common understandings and, ultimately, more research can emerge. For example, the terms complexity and chaos are often used interchangeably, and yet they are not synonymous (Cilliers 1998, Lewin & Regine 2001, McDaniel & Driebe 2001). And central to complexity science is the notion that groups of living beings or organizations, whether they are businesses or hospitals, can be described as complex adaptive systems. This concept is not captured by chaos theory.

Therefore, the aim of this paper is to contribute to the understanding of complex adaptive systems by explicating its components through a conceptual analysis. Currently, no concept analysis of complex adaptive systems exists in the literature. Rodgers and Knafl (2000) point out that the value of discussing concepts is the clarification and refinement that results with the subsequent contribution to the problem-solving efforts of a discipline.

This concept analysis will be constructed using the method recommended by Walker and Avant (1995). A modified application of their framework specifies the use of defining attributes, antecedents, consequences, and model cases. This paper will proceed using these guidelines to explicate the concept of complex adaptive systems.

Concept analysis

Historical review

To better understand the concept of complex adaptive systems, we must examine the intellectual history from which it springs. It is useful to put this evolving set of powerful ideas into an historical context to fully appreciate the state of the science in the early 21st century. Some major scientific developments have shaped and informed the historical framework of complexity science.

The first layer of this historical scientific framework emerged in the early decades of the 20th century. The work of physicists in quantum theory and the subatomic world of protons, neutrons, and electrons, based on the revolution in science begun by Albert Einstein, advanced science beyond the 18th century's emphasis on reductionism. In exploring the subatomic world, scientists made some startling discoveries: matter is not the hard mass that operates from the principles of gravity and Newtonian physics. Indeed, at the subatomic level, matter can take varying forms, either waves or particles. And what determines whether an electron is a wave or a particle depends upon the electron's relationship with other subatomic particles (Capra 1982). In addition, physicist and philosopher Capra (1996) also explained that the movement and positioning of subatomic particles cannot be precisely predicted and that dynamic interactions of continual movement characterize the world at the subatomic level. Quantum theory determined that particles can only be understood in terms of their movements and the resulting dynamics that occur as molecules interact. Capra (1982, p. 81) expressed this thought in poetic terms: 'As we penetrate into matter, nature does not show us any isolated basic building blocks, but rather appears as a complicated web of relations between the various parts of a unified whole'.

Another major contributor to complexity science was a seminal physicist, Ilya Prigogine, Belgian physicist and Nobel Prize recipient in 1977, who identified that the second law of thermodynamics of inexorable decay and random disorder was not the complete story of how processes in nature operate. Prigogine and others in the 1960s identified that in the real world atoms and molecules are almost never left to themselves; if enough energy flows from the outside, the tendency to degrade is partially reversed, and indeed, a new pattern of complex structures will spontaneously organize (Waldrop 1992, Capra 1996).

Prigogine drew on the work of French physicist Henri Benard who discovered that heating a thin layer of liquid resulted in an organization of new structures. As heat increased on the liquid and reached a certain critical value, conduction was replaced by convection, and a striking pattern of hexagonal cells appeared that resembled honeycombs (Capra 1996). This process of increasing heat was described as moving the system far from equilibrium, meaning far from uniform temperature throughout the liquid, and into a 'critical point of instability, at which the ordered hexagonal pattern emerges' (Capra 1996, p. 87). This process of self-organizing is not limited to laboratory experiments. In addition, sand dunes and snowfields can show hexagonal patterns from the flow of warm air away from the surface.

Building on Prigogine's work on non-equilibrium thermodynamics and the principle of self-organization, other scientists have noted a particular characteristic of self-organization: no one external designer or manipulation from some centralized source of control directs these new patterns (Cilliers 1998). This aspect of the science is particularly characteristic of complex adaptive systems and is one striking example of how this new generation of systems theory differs from its predecessors of earlier decades.

Moving beyond physics and the work of Prigogine, Cilliers (1998), philosopher and research engineer in computer modelling, explained self-organization from the biological perspective. He noted that a system not only must receive, process, and retain information; it also must respond and produce some form of output as well. This process can result in a form of internal structure that is the result of complex interactions between the environment and the system's history and present state. For example, Cilliers (1998, pp. 88–90) cited the example of fish behaviour, which is also an example of a complex adaptive system:

> The condition of the fish would depend on a large number of factors, including the availability of food, the temperature of the water, the amount of oxygen and light, the time of the year, etc. As these conditions vary, the size of the school of fish will adjust itself optimally to suit prevailing conditions, despite the fact that each individual fish can only look after its own interests. The system of the school as a whole organizes itself to ensure the best match between the system and the environment. This organization is also adaptive in the sense that the school will be sensitive to changing conditions in the light of past experience. There is no agent that decides for the school what should happen, nor does each individual fish understand the complexity of the situation. The organization of the school emerges as a result of the interaction between the various constituents of the systems and its environment.

The final historical scientific layer that provided the foundation of complexity science involved the principles from chaos theory, most importantly that of non-linear relationships and actions. Specifically, Edward Lorenz, meteorologist at the Massachusetts Institute of Technology, in 1963 identified the impact of changing only a few decimals in weather modelling on the overall result. Lorenz ran his computer model of weather in the middle rather than at the beginning, and he used six decimals instead of three. These seemingly small changes had a large effect on the results and laid the groundwork for the mapping of chaos mathematically. The discovery was characterized as the fact that small changes in the initial characteristics of an active system can dramatically affect the long-term behaviour of that system. This is often referred to as the 'butterfly effect'. If a butterfly flaps its wings somewhere in the world today, there will be a hurricane somewhere else at some future point (Haigh 2002).

Indeed, weather is the classic example of the non-linear world, unlike the linear world of spacecraft trajectories that can be plotted and predicted. Weather has many components, interacting in ways that are impossible to predict in advance. Other examples of non-linearity abound: ecosystems, economic entities, developing embryos, the human brain: 'each is an example of complex dynamics that defy mathematical analysis…' (Lewin 1999, p. 11).

This concept of non-linear relationships has been a large component of the application of this emerging science of complexity in economics, biology, and meteorology. Non-linear relationships are often the major concept used when scientists discuss chaos theory. However, although mathematical descriptions of non-linear relationships are quite valuable, they do not capture the structure and organization that is characteristic of complexity science in general and complex adaptive systems in particular.

It is not uncommon to see chaos and complexity used as synonyms, although Cilliers (1998) would argue that they are not the same. Specifically, chaos theory has much to say about the sensitivity to initial conditions; whereas with complexity there are always a large number of interacting components that are not so affected by initial conditions. Cilliers (1998, p. ix, 13) elaborates:

> It is exactly the *robust* (italics in the original) nature of complex systems, their capacity to perform in the same way under different conditions, that ensures their survival…My claim is rather that chaos theory…does not really help us to understand the dynamics of complex systems…it is probably most appropriate to say that chaos is a subset of complexity.

Other writers have validated Cilliers's point that complexity speaks to the order that emerges from a large number of interacting members of a system (McDaniel & Driebe 2001).

Defining attributes

A critical component of a conceptual analysis, according to Walker and Avant (1995), is the identification of defining attributes. For the concept of complex adaptive systems, Plsek and Greenhalgh (2001, p. 625) provided a useful definition:

> A complex adaptive system is a collection of individual agents with freedom to act in ways that are not always totally predictable, and whose actions are interconnected so that one agent's actions changes the context for other agents. Examples include the immune system, a colony of termites, the financial market, and just about any collection of humans, for example…a primary healthcare team.

The attributes and precise characteristics of a complex adaptive system are elucidated by Cilliers (1998, p. 3–5) to include the following:

- A large number of elements interact in a dynamic way with much exchange of information.
- These interactions are rich, non-linear, and have a limited range because there is no over-arching framework that controls the flow of information.
- Complex systems are open systems with feedback loops, both enhancing, stimulating (positive) or detracting, inhibiting (negative). Both kinds are necessary.
- Complex adaptive systems operate under conditions far from equilibrium, which means there is continual change and response to the constant flow of energy into the system. 'Equilibrium is another word for death' (p. 4).
- Complex systems are embedded in the context of their own histories, and no single element or agent can know, comprehend, or predict actions and effects that are operating within the system as a whole.
- Complexity in the system is a result of the patterns of interaction between the elements.

More than one author has cited free-market economies as classic examples of complex adaptive systems (Cilliers 1998, Rouse 2000). Within the international flow of money, goods and services, large numbers of independent agents act, learn, and adapt. These agents respond to rules and regulations, but there is no centralized command and control; furthermore, non-linear interactions are not uncommon. Frequently a small investment can reap a big reward. In addition, the human brain also is an example of a highly complex adaptive system with many interconnections and feedback loops. By contrast, a snowflake has an elaborate and beautiful pattern with a large amount of elements interacting within its structure. There is no external decision as to the position of the molecule in the snowflake, but there are no feedback loops and no evolution. A snowflake is not an open system; it cannot adapt to its environment. 'A snowflake, although wondrously complex in appearance, is only complicated' (Cilliers 1998, p. 5).

Antecedents and consequences

Two other important components in a conceptual analysis are the identification of antecedents and consequences, according to Walker and Avant (1995). The major antecedents in a complex adaptive system are the individual agents: for example, the people who make up the staff of a hospital or a cultural group, the ants in an ant colony, the individual cells that comprise the human immune system. However, the agents also must be able to interact; a large number is a necessary, but not a sufficient condition. Grains of sand on a beach do not constitute a complex adaptive system. A large number of agents with the potential to interact constitute the major antecedent required for complex adaptive systems.

Adaptation (or emergence, in the language of complexity) is the major consequence. Emergence is often referred to as a holistic phenomenon because the whole is more than the sum of the parts and is produced when agents interact and mutually affect each other (Lewin 1999, Lewin & Regine 2001). Emergence is also enhanced by diversity because of the greater interaction and richer patterns. Emergence is also often seen in crises – when groups rise to the occasion to organize and adapt to the demands of the hour. The challenge of management in nursing and health care is to cultivate creative, emergent behaviour in times that are not crises.

Model case

Walker and Avant (1995) recommended the description of a model case to capture the critical attributes of the concept under study. The model case cited below came from the healthcare literature.

Horbar *et al.* (2001) and a team of 16 researchers, representing a spectrum of specialties (to include several nurses), designed a study of outcomes for patients that focused on neonatal intensive care using a multidisciplinary collaborative improvement model. Collaborative improvement as a model has been used successfully by single units or service-based teams within single institutions. This study built on that previous research by examining collaboration among a number of institutions and was a stronger design because it included a large comparison control group.

The 10 self-selected neonatal intensive care units (NICUs) were divided into two subgroups, with six NICUs targeting nosocomial infection, as measured by rates of coagulase-negative staphylococcal or other bacterial pathogens. The remaining four intervention groups focused on chronic lung disease, as measured by either death or the requirement for oxygen supplementation at 36 weeks' adjusted gestation age. Sixty-six other NICUs served as the comparison control group. The patients were infants with birth weight 501–1500 g, born at or admitted within 28 days of birth between 1994 and 1997. The 10 intervention NICUs had a total *n* of 3800 patients; the 66 control NICUs had a total *n* of 21,509 patients.

The intervention was the formation of multidisciplinary teams, who were directed by a trained facilitator over a 3-year period beginning in 1995. The teams received instruction in quality improvement, identified common goals, implemented practices based on literature reviews and conducted site visits to other medical centres, both those participating in the study and those with documented superior performance. This research was structured within the working and stated assumption that healthcare organizations are examples of complex adaptive systems.

The teams were encouraged to develop a collegial atmosphere that focused on creating uniform protocols which were most relevant to their specific units and were able to adapt 'potentially better practices' (quotations in original). The range of practices identified as useful to improve patient outcomes included: minimizing intubation days and reducing the number of heelsticks for laboratory testing. Moreover, Horbar *et al.* (2001, p. 17) noted two important interventions related to the unit culture: '(promote) developmentally supportive care, with an emphasis on minimal handling; and develop and maintain a culture of cooperation and teamwork that supports and encourages all team members to feel responsible for outcomes'.

This study documented significant improvement in patient outcomes with this collaborative improvement model compared with the control groups. Specifically, the rate of infection with coagulase-negative staphylococcus decreased in the six experimental NICUs from 22·0% to 16·6% ($P = 0{\cdot}007$). For the infants in the chronic lung disease category, the rate of supplemental oxygen at 36 weeks' adjusted gestational age decreased from 43·5% to 31·5% for the experimental NICUs ($P = 0{\cdot}03$).

The big message and finding from this study was not the merit of any particular clinical practice that improved patient outcomes. Instead, the process was the point. The authors eloquently stated: 'If any inference can be drawn, it is that active participation in structured multidisciplinary, cross-institutional, collaborative learning that leads to focused changes in local practice can lead to improvements in clinical outcomes…Such participation may…be as or more important than the specific clinical practices implemented (Horbar *et al.* 2001, p. 20). The research results, although more modest than the projected goals at the beginning of the study, did validate the findings from previous research that collaborative quality improvement interventions can positively affect patient outcomes.

How does this study qualify as a model case of complex adaptive systems? It involved numerous agents who self-organized in order to consciously improve the rich interactions and interconnections that already existed in hospitals. There was much emphasis on the group as the tool of intervention, as opposed to a single provider or leader. No one predicted or controlled the results of these interactions. However, these collaborations were behaviours that constituted positive adaptations to the healthcare challenges presented by neonates. Those involved in the application of the principles of complex adaptive systems to hospital settings recommended that the goal of leaders should be to build relationships as a key method to solving problems (Anderson & McDaniel 2002).

Relevance to nursing

Complexity science is an exciting new chapter in the book of systems thinking and, as such, has considerable relevance to nursing. Systems thinking has a rich tradition in nursing. A systems perspective was articulated in the mid-20th century in the United States of America (USA) by Dorothy Johnson, who introduced a behavioural system model in 1959 (Fawcett 2000). Johnson's model emphasizes holism – individuals are active, not reactive, and adjust to their environments. The role of nursing is to supply assistance to individuals and families with disturbances in systems balance.

Additional US nurses continued the tradition of articulating a systems view of the world and nursing. Imogene M. King proposed a General Systems Framework in the mid-1960s that discussed three interacting systems – the person, the interpersonal, and the social system. She emphasized that such systems are open, dynamic, and interacting, connected by communication links (Fawcett 2000).

What is already known about this topic

- Complexity science is an emerging field in a wide range of disciplines, from physics to biology to health care.
- Diverse agents interact in unpredictable, interconnected ways that cannot be controlled in a centrally managed manner.
- Interactions produce creative adaptations that emerge, often during times of great change or crisis, referred to as the 'edge of chaos'.

What this paper adds

- Complex science and chaos theory are often used interchangeably; they are not the same.
- Chaos theory is a subset of complexity science.
- Healthcare leaders will enhance patient care outcomes if they focus on relationships and develop connections among staff. Patient outcomes are enhanced when these principles are applied.

Martha E. Rogers advanced systems thinking in US nursing with her 'Science of Unitary Human Beings' that was presented at a major conference in 1978. Although more abstract than earlier models, Rogers drew on an understanding of physics by discussing energy fields and the notion that the person and the environment are irreducible, indivisible wholes (Fawcett 2000).

Finally, Sister Callista Roy, with her Adaptation Model developed in the early 1970s, also built on earlier general systems theory and the work done by Dorothy Johnson. Roy acknowledged the growing body of knowledge in quantum physics by noting that living systems were both non-linear and complex processes of interaction.

This rich tradition in nursing that has emphasized connections and interactions within a systems paradigm continues today. Complexity science merely represents the next stage in understanding how systems operate. Anderson and Issel, both professors of nursing, and McDaniel, professor of management (2003), advanced the tradition of systems research with their studies that investigated complexity science. For example, these researchers identified nursing homes as complex adaptive systems. They hypothesized that management practices that encouraged interaction, learning, and innovation facilitated the development of relationships and cooperation among staff in nursing homes, and these relationships ultimately affected patient care outcomes. Anderson *et al.* (2003) measured communication openness and participation in decision-making among other variables and correlated these with nursing home resident outcomes such as complications of immobility and fractures. The findings supported the hypothesis that management practices that facilitate self-organization contribute to better resident outcomes.

An additional example of a real-life hospital environment and a nurse leader implementing the principles of complexity science was described by Lewin and Regine (2001). The writers identified a hospital in north-central New Jersey that was led by a chief executive officer who believed in the principles of complexity science.

The director of nursing also believed that the principles of complexity science could help solve tough problems, and she tackled the issue of long admission times using those concepts. In the early 1990s at this hospital, it could take up to 20 hours between the time patients entered the hospital until the time they received a first dose of antibiotics. Obviously, this was unacceptable. She set up a task force made up of volunteers from all departments because diverse elements are critical to effective self-organization. Only one simple rule was laid down for the task force: all admissions were to be done within an hour. Within 3 months, admissions were down from 20 hours to 80 minutes through a pilot project known as 'express admissions' (Lewin & Regine 2001, p. 80). The leadership approaches involved in creating this success included 'direction without directives…listening to the front-line people…support along the way, and…getting out of their way' (Lewin & Regine 2001, p. 81). Such results indicate the value of empowering a diverse group with less control and direction from the top so that intense interactions could produce creative results. Although empowerment is not a new idea, complexity science helps us better understand why it works.

Conclusions

In summary, the concept of complex adaptive systems is crucial to an adequate understanding of the emerging field of complexity science. The concept represents the dynamic interactions of diverse agents who self-organize and produce adaptations that emerge in ways that can neither be predicted nor controlled. Applications in health care and management have been studied and validated in the literature. The application of the understanding of health care as a complex adaptive system involves cultivating an environment of listening to people, enhancing relationships, and allowing creative ideas to emerge by creating small non-threatening changes that attract people.

The ancient Greeks taught us to look for patterns in life and nature. Nursing has a long, rich tradition of appreciating patterns, of recognizing and valuing systems. An understanding of complex adaptive systems will no doubt serve nursing and health care in the 21st century.

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References

Anderson R. & McDaniel R. (2002) Managing health care organizations: where professionalism meets complexity science. *Health Care Management Review* **25**(1), 83–92.

Anderson R., Issel M. & McDaniel R. (2003) Nursing homes as complex adaptive systems. Relationship between management practice and resident outcomes. *Nursing Research* **52**(1), 12–21.

Capra F. (1982) *The Turning Point*. Bantam Books, Toronto.

Capra F. (1996) *The Web of Life*. Anchor Books, New York.

Capra F. (2002) *The Hidden Connections*. Doubleday, New York.

Cilliers P. (1998) *Complexity and Postmodernism: Understanding Complex Systems*. Routledge, London.

Fawcett J. (2000) *Analysis and Evaluation of Contemporary Nursing Knowledge: Nursing Models and Theories*. F.A. Davis, Philadelphia, PA.

Haigh C. (2002) Using chaos theory: the implications for nursing. *Journal of Advanced Nursing* **37**(5), 462–269.

Horbar J., Rogowski J., Plsek P., Delmore P., Edwards W., Hocker J., Kantak A., Lewallen P., Lewis W., Lewit E., McCarroll C., Mujsce D., Payne N., Shiono P., Soll R., Leahy K. & Carpenter J. (2001) Collaborative quality improvement for neonatal intensive care. *Pediatrics* **107**, 14–22.

Lewin R. (1999) *Complexity: Life at the Edge of Chaos*, 2nd edn. University of Chicago Press, Chicago, IL.

Lewin R. & Regine B. (2001) *Weaving Complexity and Business: Engaging the Soul at Work*. Texere Publishing, New York.

McDaniel R. & Driebe D. (2001) Complexity science and health care management. *Advances in Health Care Management* **2**, 11–36.

Plsek P. & Greenhalgh T. (2001) The challenge of complexity in health care. *British Medical Journal* **323**, 625–628.

Porter-O'Grady T. & Malloch K. (2003) *Quantum Leadership: A Textbook of New Leadership*. Jones and Bartlett, Boston.

Rodgers B. & Knafl K. (2000) *Concept Development in Nursing*. Saunders, Philadelphia, PA.

Rouse W.B. (2000) Managing complexity: disease control as a complex adaptive system. *Information •Knowledge• Systems Management* **2**, 143–165.

Stacey R.D. (1992) *Managing the Unknowable*. Jossey-Bass, San Francisco, CA.

Stacey R.D. (1996) *Complexity and Creativity in Organizations*. Berrett-Koehler, San Francisco, CA.

UMI Dissertation Express (2004) Retrieved from http://www.lib.umi.com/dxweb/results on 7 March 2004.

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

Walker L. & Avant K. (1995) *Strategies for Theory Construction in Nursing*. Longman, NJ.