doi:10.1093/fampra/cml011 Family Practice Advance Access published on 5 April 2006

Wanted—new methodologies for health service research. Is complexity theory the answer?

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Kernick D. Wanted—new methodologies for health service research. Is complexity theory the answer? *Family Practice* 2006; **23**: 385–390.

Despite a recognition that health service research has failed to make its full contribution to health service improvement, the fact that evidence is not widely accommodated into practice is seen as a failure of communication rather than the inappropriate application of a particular form of investigation. Dominant theoretical frameworks still retain the fundamental idea that order needs to be somehow created by external forces and that organizational issues will inevitably yield to more collection of data and the application of increasingly sophisticated analytical techniques. This paper explores alternative perspectives and methodological opportunities that arise from viewing health service as a complex non-linear system. This approach may offer new research insights that more accurately reflect underlying mechanisms and may help to explain the limitations of current analytical techniques.

Keywords. Complexity, health service research, methodology.

Introduction

"All models are wrong but some are useful."

We need to make sense of the world and act. To do so we simplify our environment by constructing models, creating reality around bundles of related assumptions. These assumptions categorize our experience searching for relationships and regularities. Our models powerfully influence how evidence is collected, analysed and understood. Because models simplify reality they often lose intuitive insights and the use of metaphor helps to retain this information. Metaphor brings together two areas of experience, treating one as if it had the features of the other applied to it. It offers a framework to think and act differently.

Health service research draws upon a wide range of models to facilitate the allocation of limited resources against criteria of effectiveness, efficiency and equity. Due to the success of medical science and the influence of evidence-based medicine, it was inevitable that methodologies predominately based on inferential statistics and the randomized controlled trial would be applied to more complex systems such as health care delivery. The confident assumption is that a simple relationship exists between cause and effect in a system that can be understood by reducing it into its component parts.

This paper offers an alternative perspective and describes models and metaphors that have been developed under the general heading of complexity theory. It is constructed in three parts. The first section suggests that the impact of health service research has not been commensurate with the resources invested in it and that the assumptions of the predominate research models are too simplistic to reflect the realities of the health care environment. The second section outlines some general principles of non-linear systems or complexity theory with an emphasis on self-organization. The final section explores complexity implications for health service research from both broad and more specific perspectives.

The evidence-based medicine tail wags the health service research dog

In 1992 an NHS Research and Development initiative was established to correct the 'discrepancy between the technical sophistication of medical interventions and organisational dysfunction'.[1] Frameworks for the evaluation of complex interventions were to be underpinned by the randomized controlled trial set within a phased approach that reflected exactly the phases of drug development.[2]

Although more interpretative models set within qualitative frameworks and broader pragmatic approaches such as *Realistic Evaluation*[3] and *Forth Generation Evaluation*[4] have been developed, the predominant explanatory metaphor views the health service as a

Received 21 October 2005; Accepted 8 March 2006.
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machine where researchers can identify levers to engineer the system towards defined policy objectives. If the reality does not concur with the disciplinary expectation, all that is needed is more data and more analytical sophistication.

Unfortunately, the early optimism for health service research has been misplaced[5,6] and in particular, evidence-based technical solutions to organizational problems have had little impact at grassroots level.[7] Doctors seem reluctant to follow research-based guidelines[8] but implement small changes that they considered improving on existing structures.[9] These are informed by reiterative negotiation with a variety of sources and informal interactions.[10] Health care managers faced with competing objectives and uncertain cause and effective relationships find relating ends to means highly problematic and encounter substantial barriers that cannot be overcome by methodological refinements or the collection of greater volumes of data.[11]

Although there has been an acknowledgement of limitations in the current health service research programme and broader evaluation approaches have been developed, the fact that evidence is not widely accommodated into practice is seen as a failure of communication rather than the inappropriate application of a particular form of investigation[12]. An alternative explanation would be that prevailing research models over-simplify the complex environment they seek to describe and manipulate. Could models based on the study of dynamic non-linear systems that have already been successfully applied to a large number of physiological systems[13] reflect more accurately the real world of health care delivery and offer new opportunities for methodological development?

Some general principles of complexity theory

From complicated to complex systems

The dominant models of health service research sit within the Newtonian framework of modern science. The essential characteristics of this approach are

- Linearity—there is a simple relationship between inputs and outputs. Small inputs have small effects, large inputs have large effects.
- Reductionism—although systems may be complicated but they can be understood by breaking them down into their component parts. The behaviour of a system can be inferred from an analysis of its component parts. Similar subsystems will behave in similar ways irrespective of context.
- Determinism—the future of a system can be predicted with certainty. As the future can be predicted, problems can be formulated as the making of a rational choices between alternative means of achieving a known end. More information leads to a more accurate analysis.
- Impartiality—an observer can stand outside the system without being influenced by it and engineer it towards defined objectives.
- Thenatural state of a system is at equilibrium; disturbances to equilibrium are controlled by negative feedback.

What is complexity?

Complexity science adopts a model that views systems as a network of elements that exchange information in such a way that change in the context of one element changes the context for all others. Complexity is the pattern of behaviour that emerges from the interaction of elements that respond to the limited information they are presented with.[14] The organizational metaphor changes from a machine to an eco-system of co-evolving elements.

The study of complex systems originated in the late 1980s and described the behaviour of computer-based network models.[15,16] By the turn of the decade similar themes were being explored across a very wide range of disciplines which inevitably led to problems in a number of areas. For example there is a lack of consensus over definitions and terminology—45 definitions of complexity have been identified![17] Difficulties also arise when insights and metaphors developed from one disciplinary perspective are applied inappropriately to another. For example, humans in organizations behave very differently from mathematical equations in computers or animals in eco-systems.

The essential characteristics of the complexity model from the perspective of health care are[18]

- Complex systems consist of a large number of elements that interact. Interactions are predominately short-range with information being received from near neighbours. However, the richness of network connections means that communications will pass across the system but will be modified on the way.
- There are reiterative feedback loops in network interactions. The effects of an elements action are recursively fed back to the element and this in turn affects the way the element behaves in the future. Negative (damping/stable) and positive (amplifying/unstable) feedback give rise to non-linearity which is the unique feature that makes a complex system different from a complicated system. These non-linear instabilities lead to novelty and innovation and make the future behaviour of such systems unpredictable.
- Due to non-linear characteristics, small changes in one area can occasionally have large effects across the whole system. This has been called

the 'butterfly effect'. (A butterfly in New York can flap its wings and cause a hurricane in Tokyo.) For example, the riding accident of the actor Christopher Reeves had a large but probably inappropriate impact on the redistribution of research funding into spinal injuries in the US.[19] Conversely, large influences may only have a negligible impact. *The Health of the Nation* initiative was a major strategic initiative designed to influence the health of the public but had little impact on the targets it sought to influence.[20]

- The system is different from the sum of the parts. In attempting to understand a system by reducing it into its component parts, the analytical method destroys what it seeks to understand. The corollary is that the parts cannot contain the whole and any one element cannot know what is happening in the system as a whole. Therefore, no one can stand outside the system and hope to understand and engineer it to a pre-determined future as approaches to organizational change in the NHS have repeatedly demonstrated.
- The behaviour of complex systems evolves from the interaction of agents at a local level without external direction or the presence of internal control. This property is known as emergence and gives systems the flexibility to adapt and self-organize in response to external challenge. Emergence is a pattern of system behaviour that could not have been predicted by an analysis of the component parts of that system.
- Complex systems often operate away from equilibrium and multiple equilibrium is possible. Equilibrium states are invariably suboptimal.
- It is difficult to determine the boundaries of a complex system. The boundary is often based on the observer's needs and prejudices rather than any intrinsic property of the system itself. For example, primary care practitioners find it difficult to define the boundaries between health and social care in their work but these organizational demarcations have historically been rigorously enforced.
- History is important in complex systems. The past influences present behaviour. For example, it would be unwise to plan new primary care structures without a recognition of what has gone before.

Figure 1 shows some contrasting approaches to complexity. Figure 2 summarizes some important concepts that are emphasized by different disciplines.

- *Simple complex systems* – the manner in which information is processed by individual elements does not change with time. For example, a biochemical reaction.
- *Complex adaptive systems* – the processing of information by individual elements changes with time as they learn and adapt in response to other elements. For example, evolutionary computer programmes, biological systems. Complex adaptive systems need processes that both generate and prune variation to evolve.
- *Complex social systems* – organisations are studied as complex social systems in their own right, not as metaphors or analogies of physical, chemical or biological systems.
- *Complex responsive processes* – the focus of study is on the interaction between individuals at the local level from which an unpredictable future emerges.

FIGURE 1 *Some approaches to the study of complex systems*

Concept	Feature	Some key disciplines
Auto-catalytic sets[21]	Adopts the perspective of systems in which one element catalyses the interaction of others which in turn catalyses the original element.	Ecology, biology.
Dissipative frameworks[22]	Focus on system properties that operate away from equilibrium where bifurcation points can occur spontaneously leading either to instability or to a new level of order that requires more energy to sustain it.	Physics, chemistry.
Chaos theory[23]	Focus on the mathematics and geometry of non-linear systems that are sensitive initial conditions.	Mathematics, physics, physiology.
Self-organised criticality[24]	Studies systems that self-organise such that each element is optimally fit at a level that does not disrupt the fitness of others in the network.	Ecology, organisational studies.

FIGURE 2 *Some complexity concepts and disciplines where they form a focus of investigation*

Self-organization and self-organized criticality

From the perspective of health care, self-organization is a key feature. In complex systems, patterns of global structure arise from interaction of low-level processes that cannot be predicted in advance from the properties of the system elements or their rules for interaction. Spontaneous self-organization can occur without central direction or control when systems are pushed away from equilibrium.

A special case of self-organization is known as self-organized criticality. (Sometimes termed 'edge of chaos'.) Here each element is optimally fit at a level that does not disrupt the fitness of others in the network.[25] This area has been defined as the transition band between disorder and predictable stability and theoretical research has suggested that it is here where systems are maximally fit and adaptive.[25] Network connections are neither too loose where they are unable to retain system memory or consolidate gains nor too tight where they cannot innovate and adapt.

This concept runs against traditional organizational thinking that emphasizes central control and the ability of systems to be engineered towards pre-defined goals within a framework of incentives and punishments. From a practical perspective, precursors for self-organization in human systems are shared principals, connectivity, feedback, receptive context, system memory and interdependency.

An important but contested observation is that self-organizing systems obey power-laws. This phenomenon has been identified in a wide range of systems and is claimed to be a marker of self-organization.[26] Power-laws describe relationships between the size of an event (x) and its frequency (y) such that

$$y = \mathrm{c}{\cdot}x^{a},$$

where c and a are constants.

Extreme events occur more frequently than in normal distributions where events are assumed to be independent. Because the explanation of the generative processes is the same across all levels of analysis, similar power-laws are found at different levels of system scale. The implication is that frameworks based on inferential statistics that assume independence of elements have limited relevance when applied to systems dominated by a dynamic interconnectivity.

Implications of a complexity perspective for health service research

Broader insights for health service research

From a broader perspective, complexity theory challenges the positivistic framework that dominates health service research—a confident assumption that there is one correct organizational solution towards which research will inevitably converge. Firstly, it cautions against a reductionist approach in health care in all but the simplest of systems—breaking a complex system down into its individual elements inevitably destroys what we seek to understand. Prevailing statistical models which by their nature are aggregative and assume independence of system elements may have limited utility in the analysis of complex systems. Secondly, it emphasizes the importance of understanding what creates patterns of order, how these patterns evolve and self-organize and how they might be modulated. Thirdly, the focus shifts to the importance of the interaction between system elements rather than the elements themselves or the outcomes they produce.

These conceptual shifts have three practical implications. Firstly, we need to be aware that complex systems usually respond to change by reconfiguring themselves close to their original state but when transformation does occur, the size of the change invariably bears little relationship to the size of the trigger. For example, major efforts to change one part of the system such as waiting lists may not effect long-term change as adjustment will restore the system to its original state. We should be cautious when introducing measures that do not recognize the complex nature of the health care system.

Secondly, the focus shifts to research undertaken as a dialogue within a socially constructed framework rather than an expert activity.[27] Techniques such as action research[28] and knowledge utilization[29] emphasize collective sense-making through which knowledge is negotiated and constructed by stakeholders within 'Communities of Practice'.[30] More radical approaches focus on the quality of inter-personal relationships in an organization and question whether knowledge can be codified and managed.[31] From this perspective the faculties of mind and the resources of language may be best suited to the expression of complex problems and appropriate emotions are useful in showing us what we might do and also morally valuable in their own right.[32] For example, it has been argued that the failure of the rationing agenda has been due to overlooking the importance of conversational competence amongst decision-makers from which solutions emerge that are not optimal but that satisfy the constraints of the system, rather than current approaches reflected in an increasingly methodological driven agenda and the futile search for rationing frameworks that do not exist.[33]

Thirdly, the emphasis shifts to research approaches underpinned by the concept of continued learning.[34] Here, outcomes are not a final solution to a problem but a learning that leads to a decision to take certain actions in the knowledge that this will lead not to a problem being solved but to a new situation in which the recursive learning process can begin again. These themes have been developed from a non-linear perspective elsewhere with the warning that the current vogue of PDSA cycles are too mechanical in situations where processes are complex.[35]

Specific insights for health service research

The insights and metaphors of complexity theory offer alternative frameworks for the development of qualitative investigation. For example, complexity theory can provide a coherent theoretical basis for understanding the practitioner consultation that may prove useful to clinicians[36] and has been used to understand changes in individual primary care practices.[37]

From a management perspective, insights have been suggested in areas such as leadership, education and governance.[18] The perspective of complex responsive processes draws upon analogies from complexity theory and focuses attention on communicative interaction and power relating as organizational members co-create organizational futures together. The emphasis is on the spontaneous and improvizational nature of relating. This leads to profound insights into organizational behaviour that contrast markedly with the current culture of target setting and control.[31]

A wide range of quantitative approaches based on non-linear systems theory are being developed[38] where the investigative focus is on the dynamics of systems rather than an artificial static. For example, non-linear variability analysis can provide alternative approaches to describe and evaluate properties of systems that are changing with time;[39] pattern recognition techniques have been advanced that offer alternative strategies for health care analysis and improved prediction of outcomes in situations of high uncertainty;[40] approaches to controlling non-linear systems have been described across a wide range of applications such as the study of population dynamics to problem solving.[41]

A number of studies have found numerical evidence of chaotic dynamics in organizational processes.[42] Other behaviours of complex systems such as power-laws offer interesting investigative possibilities. NHS waiting lists[43] and primary care back pain consultations[44] demonstrate this behaviour leading to important implications for current attempts to engineer health systems based on linear thinking. Power-law scaling may also be used to predict behaviour over longer terms using short-term data.

Finally, computer-based models are being developed that claim to integrate the findings of health service research and inform policy by capturing behaviour at an aggregate level while reflecting the underlying recursive behaviour of individuals.[45] For example, agent-based modelling is an approach underpinned by complexity principles whereby the model is specified at the individual level of the elements involved in the system based on sets of rule-based relationships that are adaptive and can change with time rather than descriptions of its macro level behaviour. This technique has been extended into approaches where non-linear models are used in an exploratory way to foster conversations about possible impact of behaviours and ultimately to lead to change in organizational behaviour.[46]

Conclusion

Complexity theory is in its very early stages of development. The convergence of similar themes from many different disciplines has presented problems with terminology and the development of an integrated conceptual framework. There is also the potential for insights and metaphors developed in one discipline to be inappropriately applied to another. These problems have inhibited the development of a coherent body of thought and the emergence of an over-arching general theory but with time, these problems are likely to be resolved.

Some commentators have more fundamental concerns seeing little more than intuition already contained in popular wisdom and homely common sense.[47] Others suggest that evolving programmes should be treated leniently as they may take decades before they achieve empirical success. Even false models may point out new directions, articulating new ideas or providing interesting vehicles for further scientific exploration, helping to de-familiarize deeply entrenched styles of reasoning.[48]

Perhaps a more realistic perspective is to see complexity theory complementing existing approaches but alerting us to the importance of matching the research approach to the context and complexity of the environment to which it is applied. An important first step is to recognize the limitations of the dominant research discourses—the assumption that order needs to be created by external forces and that the certainty of structures seen in hindsight offer a central understanding for the emergent order that frames living forward. To be more receptive to approaches that view research not as an endeavour to configure the health service against detailed criteria, but to establish the context where the system will self-organize within a framework of broader policy objectives.

My suggestion is that insights from complexity theory resonate with the way in which health service members view the world and offers a framework within which we can articulate and explore our intuitive insights. A limited evidence base underpinned by methodologies that reflect underlying organizational mechanisms is more likely to get us to an approximation of where we want to be rather than an untenable pursuit of rigorous methodological frameworks based upon naïve assumptions where the thinking is wrong.

Is complexity theory the answer to the limitations of current research methodologies? It will be a decade before we can begin to answer that question. But in the meanwhile, a complexity research programme will need to encourage development in a number of areas:

- Better statistical tools to identify and analyse non-linear systems with an emphasis on following their dynamics rather than analysis of an artificial static.
- The development of experimental work to support theoretical constructs and identify their usefulness.
- A need for all disciplines involved in health service research to re-examine their core frameworks from the perspectives that complexity offers.

- Better tools that promote systematic thinking and that are accessible to those who actually deliver health care.
- More widespread application of models that encourage dialogue between all stakeholders in the health economy.

Over 60 years ago, the economist Keynes suggested that ‘we need to invent wisdom for a new age and that in the meantime, we must appear unorthodox, troublesome and dangerous’. The science of complexity may or may not be this new wisdom that we seek. If it only sensitizes us to the inter-play of patterns that perpetually transforms our systems against all attempts to the contrary, it may just help us to do things a little better.

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