Complexity and Strategy (2007)

Chapter 14, The Complexity Perspective

Jean Boulton and Peter Allen

Advanced Strategic Management

A Multi-perspective Approach

Second Edition

eds M. Jenkins and V Ambrosini with N Collier

Palgrave Macmillan

Part IV

Emerging and Integrating Perspectives

CHAPTER 14

Complexity Perspective

Jean Boulton and Peter Allen

Basic principles

The notion that the world is complex and uncertain and potentially fast-changing is much more readily acceptable as a statement of the obvious than it might have been 30 years ago when complexity science was born. This emerging worldview sits in contradistinction to the view of the world as predictable, linear, measurable and controllable, indeed *mechanical*; it is the so-called mechanical worldview which underpins many traditional approaches to strategy development and general management theory (see Mintzberg, 2002 for an overview).

The complexity worldview presents a new, integrated picture of the behaviour of organisations, marketplaces, economies and political infrastructures; these are indeed complex systems as we will explain below. Some of these behaviours are recognised in other theories and other empirical work. Complexity theory is unique in deriving these concepts through the lens of a coherent, self-consistent scientific perspective whilst nevertheless applying it to everyday, practical problems.

These key principles can be summarised here:

There is more than one possible future

- This is a very profound point. We are willing to accept the future may be too complicated to know, but the notion that the way the future may evolve is, generally,*unknowable in principle* fundamentally changes our notion of reality as being something that is unfixed and emergent. The future does not yet exist; it is created and not merely discovered.

Tipping

- Organisations, economies or other complex systems may *tip* into new forms with radically new characteristics; some of these characteristics may not previously have existed. Such tipping may be triggered by small, seemingly unimportant events or changes and the new state may be different in kind from the old.

Need for interconnectivity

- Complexity theory is systemic in perspective. It asserts that organisations which allow diversity and encourage interconnectivity are more able to respond to changing environments than those which are too controlled and too finely honed around a single purpose. Indeed it demonstrates that change and creativity can *only* occur if there is diversity.

Variation as a prerequisite for novelty

- Change, evolution and innovation result from events that happen *locally* – through non-average interactions and events at particular points in time and space; the nature of these local events are not predictable from the 'average' general situation. Again, the fundamental importance of local variation is a very profound insight. Allowing this so-called micro-diversity is an essential prerequisite for change (even if the change is, ultimately, global) and local variation should not be unintentionally eradicated through too great a focus on standardisation, efficiency and a search for repeatability and control.

January-2007 MAC/ADSM Page-215 1403_985928_17_cha14

Unfixed, emergent, self-organising, co-evolving

- We are working all the time with the idea of systems that are interacting, nested, evolving, fuzzy and overlapping; nothing, neither boundaries, nor characteristics, nor communities, nor connecting forces, nor constituent elements, are fixed. It is this spatial and temporal complexity that we are at pains to embrace as it contains the potential for change. Indeed the characteristics develop essentially bottom-up, not top-down. Any attempt at global imposition will be treated by the system as merely an intervention, but whether it leads to the intended outcome is another matter; unintended consequences is a central theme.

Both–and

- Embracing the message of complexity does not infer chaos and helplessness. The conclusion is *both* to create clear intentions and actions based on the best data available *and* yet recognise that plans may not lead where intended and chance ideas and impulses we unintentionally make on the environment may work beyond our wildest dreams. Strategy development and strategy implementation become much more entwined as we see what works and build on successes. It suggests portfolios are generally preferable to too great a reliance on one theme (see Allen and Boulton, 2005; Boulton and Allen, 2004); we need *both* to exploit cash cows whilst they exist *and* to invest in potential new stars. We need constantly to scan the environment in the broadest sense for potential changes and constantly to interact with the organisation at its deepest levels to see what is really happening, for good or bad.

Before getting immersed in the technical details of complexity theory, we introduce two short case studies. The first, text messaging, is the story of an unintended strategy that was ‘pulled’ by consumers, grew massively in value over a few short years and radically changed communication processes; not a story easily explained through an analyse–plan–do–review model. The second describes how a small organisation can influence larger structures whilst both keeping to a core mission and yet being opportunistic. Both should be read with complexity theory in mind.

CASE STUDY 14.1[1]

On 3 December 1992, an engineer called Neil Papworth sent the text ‘Merry Christmas’ to colleagues at Vodafone. Texting had been invented as a way of testing mobile phones remotely. However, after the Christmas message, employees at Vodafone enjoyed sending texts to each other and interest grew. Texting was offered free by many networks, initially, as part of the mobile phone package and for the first 7 years phone owners could only send messages to people on the same network. Then someone found a loophole, which involved sending messages overseas and then back again, and the networks recognised that they would have to collaborate.

In June 1999, just under 600,000 text messages were sent in the UK. By 2004, 26 billion texts were sent in the UK alone. By January 2005, 78 million texts were sent per day. The popularity is put down to its simplicity; they are cheap, do not demand all the ritual attached to a telephone call or all the grandeur of a letter. Text messaging also came of age when it found its natural market, young people. Coupled with the arrival of prepaid phone cards in the late 1990s, texting made the money go further.

The advent of texting has had quite an impact on the communication mechanisms chosen by young people, on the development of language and on the ways parents keep in touch with their children. It is reported in Japan that texting is leading to a new form of neurosis – a fanaticism about being available. A recent (2005) report suggests that texting is replacing direct conversation amongst young people! It also creates the sense that people are always available. It is felt to be immediate, accessible, private and gives unprecedented control. Another survey suggested it has had, in the main, a positive effect on the social interactions and social skills of the young.

Texting is fast becoming a business tool. Within the banking sector the UK bank First Direct says its text message banking has proved ‘phenomenally successful’.

The following recent (2005) headlines give a sense of the breadth of the potential for texting:

9 million young people in Nigeria are to be sent texts to raise awareness of HIV/aids

A teenager is treated for text messaging addiction

The Bible has been translated into text messaging speak in Australia

Merseyside police launch a campaign urging the public to text images of vandalism to them

Malaysians vote by text for astronaut candidate

Drivers get roadwork text alerts

Police launch 999 text service for deaf people

Texting is fast taking off in Asia and in the developing world, with forecasts far in excess of those for Europe, although the Swedes send the most texts in the world per person. In the USA, texting is not popular; this is felt to be due to a large degree the fact that in the USA, local calls are free – and Americans, reputably, love to talk! The US record for texting in 1 day is 26.4 million, compared with 133 million in the UK.

It is expected that mobile phones will be used increasingly for a whole range of uses covering voice, data, pictures and video, emails and storage for both business and personal. To what extent will these extended uses take off and how will they affect the popularity of texting?

Questions to consider: Could the exponential growth in texting have been planned for or predicted? Could we have foreseen how it would appeal to the young and how it would have such a wide impact – from mobile phone sales volumes through to changing social norms? How does this story fit with traditional notions of strategic planning and what should you do to ‘manage’ in these types of markets?

CASE STUDY 14.2[2]

Social Action for Health (SAfH) is a small (£1m turnover) charity based in the East End of London (see www.safh.org.uk). It was established in 1985 and its raison d’etre is to work with marginalised communities to increase people’s ability to improve their own health and well-being. In order to achieve this, SAfH in part focuses on the relationship of these communities with the Health Service: Are the services provided appropriate? Are they provided in a way that fits the needs of the communities? Do people in these communities understand what is available and how to access the services? SAfH also teaches self-management, that is, how individuals can take more responsibility for living a healthy lifestyle and, in many cases, cope with chronic diseases such as diabetes and asthma. Part of this work is based on a method developed by Lorig and has been modified to make it appropriate for Moslem men and women.

SAfH values:

We start with the people

We encourage self-determination

We believe poor health is allied to social inequity – poverty, racism, unemployment, powerlessness

We believe in the right to overall well-being, not just absence of illness

The organisation has 96 staff, 16 of which are on short-term, project-related contracts, 10 are full-time and 70 are part-time workers, drawn from the local communities; 30 of these are health guides, as they are called, working with their communities to teach people about healthy living, about exercise routines which are culturally acceptable for those from traditional Moslem backgrounds and about how to engage with the Health Service in all its intricacies.

Strategy for such a small organisation has two interrelated strands. The first centres on sustainability. How can the organisation obtain sufficient funds to ensure projects gathering momentum and demonstrating success do not come to a premature end; equally how can the organisation per se ensure its own survival? The Executive Director reports she spends nearly 70 per cent of her time on funding applications, supported by 50 per cent of the time of one of the two other senior managers. Much of the funding at present comes from the public sector, both national and local; the organisation needs to keep abreast of changing agendas, be aware of growing and diminishing pots of money and monitor what topics are 'in fashion' in order to modify approaches and hence gain access to what money is available.

Equally, SAfH clearly has to work out how to fulfil its mission. What *are* the needs of the local communities and what methods are going to work best in order to help these communities?

These two strategic influences can pull against each other. If SAfH becomes too willing to try and track the moving targets of public sector interests and structures, it could end up with no coherent thrust and lose its focus as it manoeuvres and adapts around the hunt for funding. And of course it will become of less interest to funders if it seems too diffuse and overly reactive. Equally, if it becomes too fixed on either what communities or issues are most pressing or on what methods are best to adopt, it could end up with a laudable strategy but no money.

SAfH personnel have very strong beliefs around methodology. They believe very strongly in self-determined, community-led initiatives, training members of those communities to work with existing local structures in their own languages and respecting their own customs. They believe that the start has to be about the communities' issues as seen through their own eyes; only when the relationship has developed and trust has been established can the focus be shifted to introduce new ideas and new ways of working. They experience that it is really important to judge the pace of the enterprise: too fast and trust is not built, too slow and the hopelessness and helplessness experienced by many migrant and marginalised groups is exacerbated. One of their recurrent frustrations is that just when they perceive initiatives are really gathering pace and starting really to make an impact, the focus of funders may change and projects may end too soon, with valued and trained staff having to move on due to lack of funds.

SAfH managers have clear beliefs about change; they see the importance of the interplay between bottom-up and top-down influences. They feel strongly that change is only sustained if it captures the imagination and passion and energy of the people at the grass roots and is *shaped* by them; equally, the ideas for change and the vision of what is possible and how it might fit together requires imagination and strategic vision. This bottom-up to top-down theme (clarified in the 'spiral' model they have developed, see below) is also replicated in the stated intention for SAfH to influence strategic thinking and policy within the NHS. So a recent AGM is designed partly to show the range and effectiveness of current projects, partly not only to enthuse local participants and engender a sense of pride in what they have achieved but also subtly to influence key Health Service policy-makers and provide another perspective on the art of the possible. Their work has penetrated the most marginal of societies in a way that the NHS itself has struggled to do; for example, 7000 Bengali, Somali and Turkish/Kurdish men and women have participated in Health Guide sessions. Intentions to influence NHS policy seems to be gathering momentum, as symbolised by the fact that the Health Guides project formed the central theme for the editorial of the Chief Executive of the North East London Strategic Health Authority in a recent journal (Figure 14.1).

Questions to consider: Can such a small organisation indeed influence the NHS? Can it impact on the health and social practices of such dispossessed groups? What is the role of strategy development in such a situation and what else (relationships, power, fashion, changing social norms) might influence success?

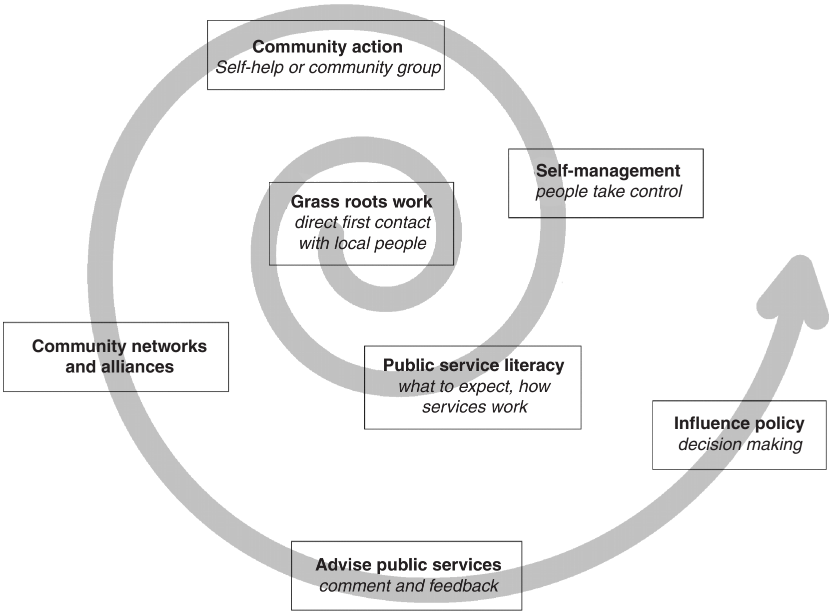

Figure 14.1 SAfH spiral of participation. © Social Action for Health – June 2005

Overview of the complexity perspective

What is complexity science?

It could be argued that many, if not most, of the tenets of complexity science do not seem in themselves to be 'new'. What *is* new, however, is that the science of complexity provides a self-consistent, coherent, scientific perspective which sheds some light on *how* seemingly distinct attributes of structures and systems are related and *why* these attributes occur (see Allen, 1990, 1994, 2001; Allen et al., 1977; Capra, 1996; Futures Special Edition on Complexity and Knowledge, 2005; Garnsey and McGlade, 2006; Goodwin, 1994; Maguire and McKelvey, 1999; Middleton-Kelly, 2003; Richardson, 2005).

This worldview stands in contrast to traditional perspectives which are, consciously or unconsciously, derived from the assumption that the world behaves like a predictable and measurable machine. Complexity theory suggests that to be successful in a fast-changing, complex and uncertain world, we must approach life in a radically different way.

Much has been written about the so-called complexity and chaos over the last 15 years (e.g. Cohen and Stewart, 1994; Gleick, 1987; Lewin, 1995; Pratt et al., 2005; Rihani, 2002); some of this writing takes the original science as 'read' and hence leaves the reader uncertain as to the validity of what is being proposed. In the following sections we seek to elucidate the core theory, returning to the fundamentals of the science. Following this historical and scientific perspective, the core fundamentals of complexity theory are explained and explored.

Where does complexity science come from?

As with many concepts that change our view of what is 'normal', work leading to the realisation that determinism (things being causal, predictable and going to plan) is not the norm came from a number of directions. This started in the late nineteenth century with some American philosophers (Buchler on Peirce, 1955; James, 1995), a mathematician (Poincaré, 1890) and several physicists, through the advent of quantum physics. Cybernetics (Ashby, 1956), General Systems Theory (von Bertalanffy, 1968), Lorenz's (1963) mathematical exploration of weather patterns, Haken's (1977) work on synergetics and Prigogine's non-equilibrium thermodynamics (Nicolis and Prigogine, 1989) built on this theme of uncertainty. They, variously, were able to develop the ideas further through the advantage of increased computer power which allowed the exploration of situations of interest through mathematical modelling.

Prigogine's work, for which he was awarded the Nobel prize in chemistry in 1977, is key (see Origogine and Stengers, 1984). He was intrigued by the mystery of evolution. How can it be, he asked, that evolution takes species into new and generally more sophisticated forms, when theories of physics seem to indicate something quite to the contrary?

Physics had at the time essentially two ideas on offer. The first built on Isaac Newton's clarification of the laws of motion of mechanical objects. It states that systems are entirely predictable and continue forever without change. The other fundamental physics theory defines 'entropy'. It states that systems will eventually 'run down', lose their diversity and structure and die.

These two theories are clearly in themselves inconsistent in their pure forms; in practice, in real life, things are not so polarised, as Prigogine recognised. The missing ingredient was the realisation that both theories applied to closed systems, that is to systems that do not interact with the wider environment in which they sit. Systems of interest in the real world are in general open, not closed; they exchange information, energy and material with their environment. In these circumstances, he was able to show that such systems do indeed have the propensity to 'self-organise', that is, to develop new structures out of either existing structures or out of so-called random chaos. Non-equilibrium thermodynamics was born and was a key step in the development of complexity theory.

As well as recognising the fundamental importance of being open to the environment, Prigogine emphasised that most natural systems are not linear and mechanical. Complex systems combine 'things' or elements which do not have to be identical; even when of the same type, the connections can be non-linear – and the elements, the forces between them and the nature of any boundaries can change with time.

The important point for those interested in social systems is that, with this most general definition of a complex system, it is impossible *not* to conclude that systems of people are indeed complex systems and can be likened to mechanical systems only in specific, stable circumstances. Therefore it is of interest for us to understand how complex systems in general behave, in order to inform ourselves how best to handle such social systems. Thus a new paradigm has evolved, called variously whole systems thinking, living systems thinking, complexity theory or chaos theory.

How is complexity science developed? Mathematical modelling

Whilst Prigogine's inspiration initially came from chemistry experiments, complexity theory in general derives its substance from studying computer models which seek to describe 'real-life' situations. There are many approaches to such modelling, and debates between practitioners often centre on the validity of various approaches and the degree to which conclusions can be generalised.

The first type of models took an equation which described a system as a whole and explored how the characteristics of the system developed with time. Lorenz's (1963) investigation of weather patterns falls into this category, and out of this the so-called chaos theory was born. Chaos theory is regarded as a subset of complexity theory. Some complexity theorists, including the authors, question the general applicability of some of the concepts deriving from this work; this will be discussed in a later section.

Then there are multi-agent models. They try to model the distinct elements and interactions in detail. A multi-agent model applied to a group of people, for example, would represent each person separately and the interactions that applied to each person would also be represented uniquely. Such multi-agent modelling is associated in particular with the Santa Fe Institute, founded in 1988 by Gell-Mann (1994) and Philip Anderson, and also characterises Allen's early work (1997), in the late 1970s and early 1980s, on cities. Multi-agent models such as these have been used to explore biological systems, ecologies and economies.

A more recent development of multi-agent models allows the agents (i.e. the constituent parts of the system) to learn over time and change their responses in the light of their experiences. This mirrors, of course, in the social realm, the reality that people do learn and change with time and do change the way they interact both with each other and with the environment. Allen (1988), Holland (1992) (through the use of genetic algorithms) and others have developed methods to explore these so-called co-evolutionary processes.

A note of warning

We must remember that systems, models of systems and boundaries are all simplifications; they are in effect figments of our imagination, helpful in that they help us label and think about a situation and dangerous if we give them too much credence. Stacey (2003) and colleagues (Stacey et al., 2002) have been at pains to point out this potential pitfall.

In practice, the notion of system merely represents a collection of 'things' related by some sort of interactions; no restrictions need be made as to the position of the boundaries or the consistency of qualities over space or time. Let us take an organisational example. By talking about a particular organisation, such a particular bank, we are suggesting that a collection of people and resources exists and is distinct from the general population and distinct from, let us say, another bank. This is obviously helpful. However, in calling attention to the 'system', that is bank A, it is not suggested that the boundaries are fixed and unequivocal (are outsourced cleaners part of the bank or not, is a wholly owned insurance company separate or not) nor that characteristics are consistent over the whole (to continue the example, is the culture in the Property division the same as in the IT division, in the north as in the south?).

If we go on to consider what happens when we try to model systems, it is true that modelling inevitably simplifies things and no modeller can ever be sure he or she is not ignoring critical aspects of the problem in the attempt to represent 'reality'. However, we must remember that thinking itself is a form of modelling, inevitably limited by language and experience. Modellers merely use modelling as an extension of thinking and use models to try out ideas and experiments, create pictures and allow inadequacies, gaps and errors to be identified. The modeller is, in general, extremely critical of his method and its results and will spend considerable time experimenting with choice of boundaries, time steps and any other simplifications.

What is reassuring for the reader and the user of the results of complex systems modelling, however, is that a number of common principles and characteristics are derived from a whole range of different methods of exploration. Whilst the details may vary, the principles in general do not. Furthermore, these principles, whilst they differ from traditionally held views as to what is scientific and how best to engage with the world, are often comfortably in accord with our personal experiences; in a sense notions derived from complexity theory tend to re-empower our common sense and native wisdom.

Principles of complexity theory

Before embarking on a description of the key principles, it is helpful to introduce the notion of 'state space'. This will allow us to describe certain aspects of complex systems thinking in a consistent fashion.

State space

State space is a well-defined and well-established tool used in mathematics and physics. It is defined as the collection of all possible states in which a system can exist. So if we consider the simplest possible mechanical system, a pendulum, its state is defined by its angular momentum. As its angular momentum does not change with time, the behaviour of a particular pendulum will be a point in state space; this is called a point attractor.

More generally, complex systems will need a number of so-called state variables to describe them and the state space will have multiple dimensions. State space can be considered as the terrain available to a system and over which it can roam. It could be applied to represent all the possible strategies an organisation could inhabit, for example, where the state variables in this case would be things such as type of technology, organisation structure, product type, supply chain and so on. What seems to happen in many cases is that the behaviour over time of a complex system settles in one region of state space – that is, a particular type of strategy, at least for a time, becomes stable, successful and self-consistent. This region is called an *attractor basin*. When the system has settled into that region it will tend to remain there; it is said to self-regulate or be homeostatic or in dynamic equilibrium.

In general state space will contain a number of attractor basins; that is more than one combination of characteristics will be stable; in our strategy example, there will be more than one group of available strategic options in the marketplace. There may also be regions of turbulence, where any possible structures do not self-reinforce and patterns of connectivity are constantly shifting and changing. The constant shifts in power and forming and breaking of structures and alliances in unstable political regimes are examples of such turbulent behaviour.

The final and perhaps the most crucial point to make about the state space 'landscape' is that it can itself change and evolve – not only through the attractors changing shape and forming new patterns amongst themselves (as the values of existing state variables shift) but more radically through the emergence of new characteristics and dimensions. This latter process *is* evolution. When we look at an evolutionary tree describing the emergence of new species or, in the economic world, we consider new technologies or working methods, we are looking at a picture of an expanding state space, with potential characteristics that did not exist before. So in a pre-amphibian world, the concept of 'legs' did not exist until there were land animals; equally, in a pre-telephone and pre-computer world, the ways of communicating were clearly much more limited than now; state space required much fewer dimensions in the past to describe the options.

So there are in effect two ways that a complex system can change behaviour. The first is that some atypical event (such as the so-called 'noise') can 'tip' the system into a new region. This could be into a turbulent region or into another attractor basin. So, relating this to the field of strategy, changes in the rules applied to chassis design for Formula One racing in 1980 'tipped' the dominant technological characteristic from engine design to aerodynamics and caused Ferrari to lose its leading position for 20 years. Equally, the death of key politicians can in certain circumstances tip regimes into periods of turbulence.

The second way a complex system can change behaviour is when the dimensions, characteristics and attributes of state space themselves change. This could occur through changes in the environment or through learning and evolution of the system per se. In this so-called co-evolutionary phase, what had been a stable attractor basin may either develop new additional characteristics or may disappear altogether. Major so-called disruptive technologies (Christensen, 1997), such as the motor car or the

Internet, which cause a radical shift in social structures and ways of life are examples of triggers which can lead to such co-evolutionary change where the whole landscape of possibilities itself re-forms.

With these concepts defined we can now explore some of the key principles of complexity theory.

Key principles

Path dependency and unpredictability; there is more than one possible future

The trajectory or path of a complex system is irreversible and non-deterministic – that is, it is impossible to retrace one's steps and end up in the same place and it is impossible reliably to predict what will happen in the future. However, that is not to say that the behaviour of a complex system is random. Beguilingly, for much of the time the path of the system will unfold in a relatively causal fashion, with the past forming quite a reliable predictor of the future. The 'problem' occurs at so-called points of tipping or bifurcation; at these points, there is more than one possible path the system could take; which path it will take may be open to guidance or influence but it is not entirely predictable; in other words at that point there is more than one possible future. What is more, it is both hard to predict when these points of bifurcation will be met as well as into which future state the system will tip when it reaches such a point. After such a 'tip' the system may have completely different characteristics than before. The relevant qualities or parameters needed to describe what is happening may be quite different than before.

This notion of path dependency is profound. Mechanical science suggests that if we work hard enough we can collect enough data to predict the future reliably, given the right methods and analytical tools. Complexity theory in contrast states that the future is created in the future and all we know at a given point in time can *never* be enough to tell us what will unfold. Modelling, scenario planning and foresighting can help us explore possible futures and craft strategies that seem likely to succeed and develop defensive contingency plans – but we can never be absolutely certain what will work and what will not.

Another important nuance is this concept of irreversibility – that there is no going back. It is enticing to feel that if the future is not to our liking we can go back to the methods and structures we had before. But path dependency tells us that even if we attempt to do this, we can never reliably return to a previous state. So, relating this to the organisational world, if we find that an adopted strategy is not giving us what we wanted, we may feel we can merely return to what we were doing previously. But the organisation itself has had a different experience; new lines of reporting and new power structures will have developed; going back will not take the organisation to the same place. In addition, the competition, customers, suppliers and distributors will have changed their expectations, choices and routines and will not seamlessly return to past behaviours.

Furthermore, if the system has tipped into a new, stable attractor basin, it may indeed be very difficult to move on or move back. For example, when one product is chosen in comparison with a competitor (such as petrol cars rather than electric cars or VHS videotape over Betamax) there can be a so-called *lock-in effect* (Arthur, 1983). The interplay of the change with the broader environment (who, to develop our example, have got used to certain technologies and the changes have spawned other related technological advancements) is such that conditions can make it virtually impossible, with time, for what had initially constituted another option to make any headway.

Small things have big effects

Conventional mechanical thinking suggests that future follows rationally from the past and that the future is influenced according to the magnitude of the relevant factors. So, for example, we would expect large firms or dominant political groups to have more impact than individuals or small players. Complexity theory suggests that the cause of change is often quirky, small and local. If a system is near the edge of an attractor basin or if the whole landscape in state space is shifting, it may not take very much to tip the system into a new form, into a new attractor basin. What causes one line of development to succeed rather than another is often dominated by chance events, actions of particular individuals, behaviour of small non-average groups or *unintended consequences* of well-thought-through 'rational' decisions. We can consider the importance of certain key historical figures, such as Hitler or Mandela or the impact of events such as September 11. Equally, if the system is 'locked in' to a stable position, it may resist change no matter what pressure is brought to bear. The impact of the knowledge that smoking causes cancer had remarkably little effect on tobacco sales for many, many years due, in part, to the position of dominance of the tobacco firms and their ability to cast enough doubt on the research findings and perhaps influence governments not to play too strong a part in health education on this point. The collective denial of smokers unwilling to relinquish 'their only pleasure' was also, clearly, part of this 'lock-in'.

Micro-diversity: The importance of 'local'

One of the most exciting and important findings of complex systems modelling is to show how creativity, evolution and change can occur *only* if there is diversity and if elements within the system are strongly inter-related (Allen and McGlade, 1987). In other words, systems or structures where individuals, to look at it from a social systems perspective, are identical and where interactions are controlled by rigid structures can neither adapt to changing circumstances nor develop new characteristics and qualities. In practice the mechanisms for evolution and change come from synergistic interactions of differing qualities that happen at certain locations. For example, if a food source in a lake disappears, it will not do so uniformly; equally the response of a particular species to a given change will not be a uniform one over the lake and over time. Different groups may try out different responses, healthier animals may survive better than weaker individuals, what happens to one species locally will depend on the response of other species and on the density of that species at a particular place. If we only consider average responses to average events or if we seek to minimise variety and control interactions we will destroy the very mechanisms that lead to change (see Kay and Schneider, 1994; Ulanowicz, 1980).

We can make an analogy with hydrodynamics, which describes flow patterns in fluids. The dynamically stable swirling patterns that occur in water going down a plug-hole or in a tornado are the slow patterns that settle down and become stable after the fast dynamics have neutralised themselves. We may never know what the fast dynamics were, and certainly the individual molecules will have no control over these patterns, but they are fundamental to what emerges at a more global level.

Snowden (2002) warns us against what he calls retrospective coherence. When we look back on events we often think we see causal links. What we may not see are the attempts at synergies that failed and the excursions the system made, which left little trace but were nevertheless vital in what transpired. Some work on evolutionary theory (Raup, 1992) similarly emphasises the importance of extinctions in the process of change and shows that evolution happens in bursts not in a gradual fashion. This is punctuated equilibrium (Gould, 1989).

Self-regulation or homeostasis

If a system is in a condition of dynamic stability, it will be robust against relatively small shifts in the environment or small changes from within and will be able to *self-regulate* (Maturana and Varela, 1987). In effect the system is stable, for a time, with respect to its own fluctuations. The conditions for effective self-regulation as for creativity generally, are where the elements of the system are free to shift and change both internally and in relation to each other, where there is diversity and rich interconnectivity. If the system is too rigid, too regimented, too standardised, such adaptability becomes difficult. With respect to state space, we are describing a situation whereby the system adapts to stay within the same attractor basin.

The mechanisms for such self-regulation result from shifting balances between positive feedback loops and negative feedback loops in the interactions between elements within a system. Take, for example, the human body. Most of the time, this is an excellent example of a self-regulating complex system (see Briggs and Peat, 2000). The state parameters, such as temperature or weight, remain steady, despite the person eating or moving from place to place. In that way the negative feedback loops are keeping the body in dynamic equilibrium. However, if the changes are too great, if the person gets a serious disease or is subjected to extreme temperatures, this dynamic equilibrium will break down; certain positive feedback loops will dominate and take the system out of control; in this example, the person may die.

The current debate (2006) on climate change is another example. Mechanical thinking suggests that climate change creeps on gradually and can be slowed down or even reversed if we make gradual incremental changes. Complexity thinking suggests that there will be a point of no return, a 'last straw', after which the self-regulatory potential of the earth to maintain temperature control in the face of non-trivial changes will not be enough to resist the tipping into a new era – and that this new era is likely to be irreversible and 'lock in' – and may not be in the best interests of the human animal. Lovelock's recent book (2006) and a recent UK government report, Tirpack (2006), suggest we may be closer to this point than we would like to think.

The dilemma is that, for stability, we want to restrict positive feedback loops and for creativity, we want to allow and enhance the possibility for synergistic positive loops between qualities within the system and allow them to grow.

Self-organisation

Self-organisation describes the situation where new emergent structures and properties may arise without being imposed from above or from without; as with self-regulation it is a distributed response of a system.

The same mechanisms are at play as with self-regulation, but in this case what may come out of the subtle shifts in the connectivity of qualities and characteristics in the system is that certain combinations of these may find new ways to interact. These new synergistic groupings (formed through positive feedback loops) may create new characteristics which start to assume dominance. Thus the set of system characteristics may *tip* into a new set; this is self-organisation and new properties are said to *emerge*. In terms of state space, we would say that the system has reached a point of bifurcation and tipped into a new attractor basin. In strategy terms we would say that a new type of strategy has been discovered – maybe due to tackling a new marketplace with the same products or changing the distribution process – but that the change has not changed the marketplace or social behaviours out of all recognition, in contrast to a co-evolutionary process, as described below.

Arthur makes the point (1999), and we would agree, that there is no a priori reason why this new form of the system may be what we wish. The process of tipping does not, as a matter of course, take the system to somewhere that is necessarily 'better' or 'appropriate'. For example, consider the novel *Lord of the Flies* (Golding, 1954). Here is an example of a loosely structured group in a new environment which did find a new form, but at the expense of one of its members. Similarly ecological systems will respond to changes in food supply by changing who eats whom – not necessarily in the best interests of the weak. So in extending these ideas into the organisational world, we must be careful not to conclude that leaderless, loose, diverse structures necessarily lead to something better – it all depends on what we regard as 'better' and from whose perspective. We thus need to encourage diversity and interconnectedness, but still develop shared intents and values; we need to monitor the way the system is changing and yet be prepared to intervene when necessary.

Co-evolution

This brings us to the final type of organisation change, where the elements themselves and the interactions between them may both evolve (Allen et al., 1985). This corresponds to the situation where the 'terrain' in state space itself shifts and changes. We are no longer moving within an attractor basin nor shifting between attractor basins; *everything* is shifting. In such processes of radical change, the way the range of possibilities re-forms itself is through an interplay between the environment, the systems within it and the elements within the systems. Co-evolution is said to occur as everything creates change in everything else in an inter-related and recursive fashion. In such circumstances, the future may bear little resemblance to the past. Such radical change is most likely when both system and its environment are least stable and most open to re-forming. Radical new technologies such as the Internet can precipitate such radical change, where the world from both social and economic perspectives can be regarded as substantially different compared with a pre-Internet world, and equally the interplay between the technology and its users has significantly shaped the development of the World Wide Web per se.

Commonly held concepts of more questionable importance, in the view of the authors

Chaos theory

Chaos theory is regarded as a subsection of complexity theory. It was developed from the work of Lorenz (1963). He showed that deterministic (i.e. predictable) but highly irregular flow patterns existed within a particular set of equations used to simulate weather systems. He found that whilst the behaviour with time *looks* random or chaotic, the solutions in fact stay within relatively well-defined regions in state space, called strange attractors. The behaviour is called deterministic chaos and should not be confused with the more general and normally accepted use of the word 'chaos' to mean 'random', totally unpredictable behaviour. Confusingly, it is this everyday, latter use of the word that is inferred by Prigogine, in his book *Order out of Chaos* (Prigogine and Stengers, 1984) and by Kaufman (1995) and others in the definition of the 'edge of chaos'. What Lorenz also showed was that the solution was very sensitive to initial conditions; this is often called the *butterfly effect*. Fractal geometry (Mandelbrot, 1977) is another derivation from chaos theory. More recently, questions have been raised as to the general applicability of these ideas deriving from deterministic chaos (see Allen, 1988; Cilliers, 1998; Stacey, 2002).

Edge of chaos

Let us start with Prigogine's phrase, 'order out of chaos'. Prigogine, in considering chemical and biological systems, placed focus on the movement from a state of molecular chaos, where there is no structure, as in a gaseous state, towards the region where spontaneous structure may form – the so-called 'order out of chaos'. The potential for this transition is due to energy being available through connection with the environment; this is referred to as 'pumping' the system. At the point where this energy flow from the outside is sufficient, spontaneous structures may appear; this is the region of self-organisation, already discussed. If the system is pumped to too high a degree, it may enter a region of turbulence. That is where structures may form and break in random fashion but do not settle into stable forms. The region of turbulence is equivalent to the behaviour of choppy water or of turbulent swirls and flows in the body of liquids. To summarise, in the regime where there is intermediate environmental 'pumping' between microscopic chaos and macroscopic chaos (i.e. turbulence), new configurations and structures can spontaneously emerge and evolve.

Let us now compare this perspective with the notion of the 'edge of chaos'. The phrase was coined as a result of work undertaken by Chris Langton using cellular automata, a particular form of multi-agent modelling (Waldrop, 1992). Langton found there was a so-called phase transition, a well-defined shift between order and chaos, in experimenting with such models. Confusingly, order, here, is taken to mean the situation where everything is in equilibrium, which is, in fact, equivalent to what is found where there is random molecular chaos! The extended region where structures can spontaneously emerge and evolve described by Prigogine accords with the notion of the 'edge of chaos' – except that the word 'edge' implies something much sharper, narrower and well defined than may be helpful.

The problem comes when we try and apply this notion to real-life situations. How might we find this region or edge? Is being there necessarily beneficial? This nascent state is felt most likely to lead to new possibilities and hold greatest potential (McMillan, 2004; Rihani, 2002). It is, however, further suggested – in applying these ideas to social systems – that groups with a minimum of structure, focus and leadership, allowing for greatest flexibility and indeed most potential for chaos are most likely to find this state. In other words, chaos is 'sold' as a precursor to change and evolution. It is with this last statement that the authors would disagree. To be somewhat technical, to have the potential for emergence and evolution, we require strong interconnectivity of the non-linear type and self-reinforcing feedback loops; not too tight and not too loose. In addition there must be some degree of 'noise' – that is random inputs, variations or some sort of non-averageness. These variations will in effect test the stability of any emerging structure and, in the event of a revealing instability, drive the system to a new structure or state.

When continuing to apply these ideas to social systems, what seems most beneficial in approaching change is to seek to shift smoothly from one attractor basin to another. The move from apartheid to non-apartheid in South Africa could be regarded as such a shift. The shift did create new structures and characteristics but it was not turbulent but constrained to some degree by the presence of Mandela and others and by the way it was handled. We must also be careful not to conclude, as exemplified by *Lord of the Flies* (Golding, 1954), that providing minimal structure together with maximum flexibility will necessarily be a 'good thing' and result in a positive outcome. Clearly too much structure will constrain the ability of a system to adapt to changing circumstances and find new solutions, but too little structure can be equally dangerous.

Simple rules

Self-organisation can be shown through simulation to be achieved through the use of so-called *simple rules* of interaction. An analogy is made, for example with termite mounds (Bonabeau et al., 1999). Termites follow simple rules of interaction and these rules allow them to modify the shape and structure of the termite mound to suit the local terrain. This is obviously an interesting process and in principle, it implies that if this notion is then transferred to organisational life and organisations are run on 'simple rules', they will be adaptable and re-shape themselves in the light of changing circumstances (see Eisenhardt and Sull, 2001). This is okay as far as it goes. Our first difficulty in putting this into operation is to try and define at what level our suggested 'simple rules' apply. Do they apply to the behaviour of individuals towards each other or to the behaviour of organisations or markets? What happens if rules contradict each other or are ambiguous?

Second, from the point of view of complexity theory, simple rules are emergent, not imposed. They are a consequence of self-organisation, not a prerequisite. We cannot know in advance what types of interactions between elements faded and failed – so choosing simple rules to apply seems problematic, even if better than imposing too great a degree of control.

Finally, we must remember that the rules termites follow still only allow them to make termite mounds! In times of fast-change the simple rules themselves may need to evolve. How do we set up situations whereby we can ensure the rules of engagement continue to evolve? Perhaps the extent that companies held up as examples of good practice in the work of Peters and Waterman (1982) did not continue for many years to succeed is an example of this difficulty.

Linking the complexity perspective to strategic management

What does a complexity theory perspective imply for strategy development?

The notion that the world, generally, is unpredictable and interconnected is hardly a surprise. What perhaps *is* a surprise is the extent to which traditional methods of strategy development are still predicated on the belief that the future is, to a large part, predictable and open to analysis.

So what does a complexity theory perspective imply for strategy development? The first point to make is that the answer to this question is *contingent* on the environment and the nature of the business. For circumstances of relative stability, to assume that yesterday's knowledge of the market, customer requirements and outcomes of previous plans will be good indicators of the future is reasonable and helpful. For example, if we are aiming to develop a strategy for dealing with car insurance claims or with retailing kettles in western Europe, it is reasonable to expect that, provided we ensure there is no relevant new technology on the horizon which could revolutionise the business, or so much adverse consumer opinion that consumers are desperate for something new, we can plan the future in traditional ways.

If, however, we are in situations where the technology or the environment more generally is unstable and fast-changing, then relying on the past to inform the future is more than unhelpful, it can be positively dangerous. Our case study about text messaging is a good example of being in this emergent, co-evolutionary phase of strategy.

In some ways, if it is possible to know which of these two extreme positions characterises a particular environment and a given business situation, then things are relatively straightforward. Either we are in an analyse–plan–do–review situation or we are focused on experimentation, agility, adaptability and co-evolution. Both extremes suggest different types of organisation structure, culture and leadership style; the first is about exploiting economies of scale, being efficient and exerting good controls; the second suggests decentralisation, networks, project teams, empowerment and innovation. Our great difficulty is that we cannot always know for how long our environment will remain stable. Are we near a tipping point? Will a single crisis event or a surge of consumer frustration or a new technology we did not take seriously suddenly tip our industry into a new era? Equally, at the opposite extreme, when will the unstable emergent market we are in settle down into something more knowable and predictable? Has the airlines' response to 9/11 now stabilised or not? Should followers in a market sector wait for the dust to settle and see what happens to the leader who changed the territory and then set up a focused strategy when the new form of the marketplace has taken shape or should followers help to shape that market and enter the fray as soon as possible? Perhaps the important point to take from this discussion is that, whatever state of play is occurring, we can never reliably know how long it will last.

To recognise that not only do we not know the answers to these questions, but there *are* no firm answers is, in itself, helpful, if frustrating. It suggests that we should regard any strategic thrust as potentially temporary and have some growing strategic shoots in the wings in case things change. It suggests we should spend effort in scanning our environment to at least do the best we can to spot potential changes that may cause tipping. This is extremely difficult to do. Sometimes, situations should, we think, tip and they do not. Consider how long it took between discovering smoking causes cancer, tobacco companies admitting smoking causes cancer and then smoking habits beginning to change. Consider how certain organisations can sometimes be that their technology will take off and it does not. The Betamax–VHS videotape battle is an example of this. Scenario planning is an effective 'scanning' and thinking process, but, again, our difficulty is that it is hard to imagine things that are radically different and have not as yet existed; even with scenario planning we can only think the thinkable, so to speak.

The other side of the coin, of course, is that sometimes strategies take off in ways which we never envisaged or even dreamt could happen. Text messaging was developed to test mobile phones remotely; it was never designed as a strategy. There is a case discussed in Gladwell's book, *The Tipping Point* (2000), about Hush Puppies shoes becoming fashionable again in the 1990s in New York, where they were used on the catwalk. Production shifted from 30,000 pairs per year in 1992 to 400,000 pairs per year in 1996 without the company either intending this as a strategy or promoting these shoes in any way; the strategy came to them.

Summary

The strategy process in the light of complexity theory starts to look something like this:

Take a view as to whether the environment for your products and services seems stable or potentially fast-changing, and take a view as to whether the status quo is likely to change.

Develop your key strategy accordingly (i.e. exploitative/mechanical or adaptive/emergent/agile or poised to respond if things suddenly change).

Have other strategic elements in play and regard these as experiments; some may take off beyond your wildest dreams; some may flop despite evidence to the contrary.

Be agile enough to back strategic threads that are taking off beyond expectations and be prepared to pull the plug on threads that 'should' work, according to the analysis, but don't.

Scan your own organisation for unintended successes, good ideas, hidden resources and be prepared to back winners even if they were not what you were intending.

Keep scanning the environment and respond and adapt to changing needs, crises that shift the status quo, new competitors, new technology and so on.

Use scenario planning and foresighting to envisage possible futures and, importantly, to identify potential early warning signs of fundamental change – but remember that you may still not think the unthinkable!

Allow some 'slack' and diversity in the organisation and beware of streamlining the organisation to too great a degree around one purpose. This efficiency minimises the ability to respond to changing circumstances or to try out something new. It can result in destroying good intrinsic capabilities which may be just what are needed in a changing and emergent market.

Recognise that sometimes the world changes beyond recognition and what worked in the past will not work in the future; sometimes adapting is the only option and yet proactive innovative strategic thrusts may also win out in changing times.

We would like to raise at this point the concept of the 'dominant firm' (Miller, 1976). This is a very beguiling concept strategically. If we are big enough, we can dominate the marketplace and control what the consumer can have and what other suppliers can give. This strategy can work very well for a time and can indeed strangle innovation and change in the marketplace. However, it seems to be the case that, in the end, the consumers' desires win. Some chink appears, typically through a tiny competitor with a new approach, and consumers vote wholesale with their feet. The ex-dominant dinosaur has little potential to adapt and often struggles to survive. It will be interesting to see (2006) whether Google is able to threaten the giant Microsoft.

How do these ideas relate to other approaches to strategy development?

Complexity theory offers a 'scientific' theoretical lens through which to view many other perspectives, derived more empirically (see Wheatley, 1992). The ideas encompass the notion of learning and adapting, with strategy viewed as an emergent process developed by learning through experience. This so-called learning approach to strategy development encompasses a sense of incremental change, however (see Quinn, 1980, and logical incrementalism). The underlying dynamic from the perspective of complexity theory may be much more sudden and dramatic if the situation in the environment is at a tipping point. So the adaptation implied in such circumstance may be more radical and extreme than the notion of learning may imply. However, the idea that implementation is in part a way of testing strategy and not separate from it is certainly of importance.

Equally, complex systems thinking is in tune with aspects of a resource-based view (see Chapter 9 for references). Complexity theory emphasises the need for maintaining a diversity of resources and recognising the resources that are hidden or unacknowledged, may indeed be the very resources that, in combination with other factors, provide the creative opportunity in a changing environment. As certain synergistic combinations of resources take precedence and others fade, factors that used to be minor and unimportant may take centre stage (see Streatfield, 2001 for an excellent case study of this concept).

In a complex systems perspective there is perhaps more focus on the interplay between organisation and environment than in much of the literature on core competencies (Hamel and Prahalad, 1989), although the notion of dynamic capabilities (Eisenhardt and Martin, 2000; Teece et al., 1997) does indeed recognise that the mechanisms through which firms accumulate and dissipate new skills and capabilities are the source of competitive advantage. Hamel and Prahalad (1989) also emphasise the concept of strategic intent. This need for this proactive assertion on the marketplace is embraced within a complexity perspective.

The idea that strategy and structure being contingent on the nature of the environment is a well-established concept (e.g. Burton and Obel, 1998; Duncan, 1972; Lawrence and Lorsch, 1967; Thompson, 1967). And a recognition of the need to study the co-evolution of firms with their environment dates back to Weber (1978), who argued that the bureaucratic form of organisation arose at a particular time of history in response to the confluence of forces of change that ushered in the industrial age. Lewin et al. (Lewin and Volberda, 1999; Lewin et al., 1999) define co-evolution as the joint outcome of managerial intentionality, environment and institutional effects and state that such studies are still rare.

Conclusion

What in particular do the authors feel complexity theory has to offer to the field of strategy development? First of all, it places central importance on adopting an integrative viewpoint and underlines the dangers of single lens perspectives; it is often in the integration of factors both within firms, between firms and with other aspects in the environment, that change, the potential for change, the likely nature of that change and indeed the possibility for no change are all held. Second, it shows that creativity and adaptation are derived locally and through allowing diversity and interconnectivity to exist; we are warned against overly streamlining and controlling strategies and structures and equally warned against too much looseness and chaos. Third, it emphasises irreversibility and the limits of replicability which brings into question the use of standard solutions and indeed too great a belief in the lessons to be gleaned from case studies.

Perhaps the most important contribution from complexity science centres around the concept of the tipping point. Change can often be fast, radical, triggered by chance or small events and irreversible. After such changes the perspectives of the past no longer hold; it is a new world with new characteristics. The strategist must try and see the signs of instability and impending shifts and tread a fine line between riding the wave and shaping the fall.

Case studies revisited

Text messaging is a prime example of a spectacularly successful innovation that never was a strategy! Text messaging was designed for testing mobile phones remotely; it was not perceived as an important new communication process by either its inventors or its manufacturers. It is an excellent example of consumer pull rather than marketing push. It was non-average consumer 'anoraks' who worked out how to beat the system by sending texts abroad and this forced the hand of the networks who were forced to allow texting between networks. This 'beating the system' – not planned and leading to a strategy adopted reluctantly – was what allowed the texting to take off in leaps and bounds with a 6000-fold increase in traffic in the UK in 6 years. The key market created itself; no one seemingly intended the market focus on young people and the market grew with very little focus or advertising. So we have a clear example of a spectacular growth created because something became accidentally available, something which a new market sector found it really liked and wanted. Manufacturers had to adapt to this growing need rather than go out to create it or even give it shape.

The text messaging story is also an example of co-evolution between the technology and marketplace; both changed in the process. Text messaging has created social changes in communication habits and parenting methods; it has changed the language; it has created a brand new market for mobile phones; it is changing business processes as well as influencing personal communication patterns. Equally, the demand for the technology has produced a response in mobile phone manufacturers in relation to tariff strategies and product design. So the strategy landscape post the advent of texting has a new attractor basin – that of young people, and the landscape as seen from the social perspective has new behaviours; these two changes have co-evolved.

We also have an example here where the world following the introduction of text messaging has new characteristics and behaviours that were not there before and could not easily have been predicted from analysing a pre-texting world. Communications in developing countries, for example, are radically different in kind and in degree to what they were before and communication processes between young people and with their parents have a completely different flow and frequency than in the past. So texting has tipped us into a new era of interaction from which, one might suspect, there is no going back.

The emerging story of *Social Action for Health* (SAfH) is an example of the need, in strategy development, to both adapt and respond to the wider marketplace and yet also to impact their marketplace with a coherent strategic focus; in this case the wider marketplace includes both the Health Service and the local communities. So this is a 'both–and' strategy which must synthesise reactive with proactive elements. The strategy also demonstrates the need to continually refine itself in the light of experience and changing strategic direction in the Health Service in particular. The strategic intent itself embraces a bottom-up approach to working with local communities at the same time as harnessing this experience to influence the Health Service to change methods and priorities. The impact of this small organisation seems out of kilter with its size and provides such a good example of a systemic and empowering way of working that it could perhaps tip the balance of opinion in the health sector and pave the way for new approaches and methodologies.

Summary

The real message of complexity is that of change – not just the superficial growth or decline of different elements in the system, but qualitative structural change involving new entities, new attributes and new possibilities, and therefore creating new threats and new opportunities. The question at its heart is this: how did things become what they are, and more importantly what might they become in the future? Can we understand what is changing around us and how it might affect us, and can we transform ourselves and our knowledge fast enough to keep up? This co-evolution of the world, of our knowledge and consequently of our aims and goals is the real framework of our existence, and it means that we must live permanently in a real-time, learning process. This means that as fast as change erodes our knowledge, we must be experimenting and exploring and re-constructing our knowledge on a permanent basis – indeed the need to do this is the only thing that will be unchanging!

Notes

1. Information derived from BBC Website.
2. Derived from internal papers and discussions with SAfH personnel.

References

Allen, P. M., 'Dynamic Models of Evolving Systems', *System Dynamics Review*, 4 (1988) 1–2.
Allen, P. M., 'Why the Future Is Not What it Was', *Futures*, 22, 6 (1990) 555–569.
Allen, P. M., 'Coherence, Chaos and Evolution in the Social Context', *Futures*, 26, 6 (1994) 583–597.
Allen, P. M., *Cities and Regions as Self-Organising Systems: Models of Complexity* (Amsterdam: Gordon and Breach, 1997).
Allen, P. M., 'What Is the Science of Complexity?', *Emergence* 3, 1 (2001) 24–42.
Allen, P. M. and J. G. Boulton, 'The Implications of Complexity for Business Process and Strategy', in K. A. Richardson (ed.) *Managing Organizational Complexity* (Greenwich, CT: IAP Publishing, 2005), pp. 397–419.
Allen, P. M. and J. M. McGlade, 'Evolutionary Drive: The Effect of Microscopic Diversity, Error Making and Noise', *Foundation of Physics*, 17, 7 (1987) 723–788.
Allen, P. M., I. Prigogine and R. Herman, 'The Evolution of Complexity and the Laws of Nature', in E. Laszlo and J. Bierman (eds) *Goals for a Global Society* (New York: Pergamon Press, 1977).
Allen, P. M., M. Sanglier, G. Engelen and F. Boon, 'Towards a New Synthesis in the Modelling of Evolving Complex Systems', *Environment and Planning B*, 12 (1985) 65–84.
Arthur, W. B., 'Competing Technologies and Lock-In by Historical Events: The Dynamics of Allocation Under Increasing Returns', *IIASA Paper WP-83-90* (Laxenburg: Austria, 1983).
Arthur, W. B., 'Coming from Your Inner Self', *Interview with W. Brian Arthur, Dialog on Leadership* (Palo Alto, CA, April 16, 1999).
Ashby, W. R., *An Introduction to Cybernetics* (London: Chapman and Hall, 1956).
Bonabeau, E., M. Dorigo and G. Theraulaz, *Swarm Intelligence: From Natural to Artificial Systems* (New York: Oxford University Press, 1999).
Boulton, J. G. and P. M. Allen, 'Strategic Management in a Complex World', *British Academy of Management Conference* (2004).
Briggs, J. and F. Peat, *Seven Life Lessons of Chaos: Spiritual Wisdom from the Science of Change* (New York: HarperPerennial, 2000).
Buchler, J., *Philosophical Writings of Peirce* (New York: Dover Publications Inc., 1955).
Burton, R. and B. Obel, *Strategic Organizational Diagnosis and Design: Developing Theory for Application*, 2nd ed (Boston: Kluwer, 1998).
Capra, F., *The Web of Life* (London: Harper Collins, 1996).
Christensen, C. M., *The Innovator's Dilemma* (Boston, MA: Harvard Business School Press, 1997).
Cilliers, P., *Complexity and Postmodernism: Understanding Complex Systems* (London: Routledge, 1998).
Cohen, J. and I. Stewart, *The Collapse of Chaos* (London: Penguin, 1994).
Duncan, R. B., 'Characteristics of Organizational Environments and Perceived Environmental Uncertainty', *Administrative Science Quarterly*, 17, 3 (1972) 313–327.
Eisenhardt, K. M. and J. A. Martin, 'Dynamic Capabilities: What are They?' *Strategic Management Journal*, 21, 10/11 (2000) 1105–1121.
Eisenhardt, K. M. and D. N. Sull, 'Strategy as Simple Rules', *Harvard Business Review*, January (2001) 107–116.
Futures 37 (7) Special Edition on Complexity and Knowledge (2005).
Garnsey, E. and J. McGlade, *Complexity and Co-evolution, Continuity and Change in Socio-economic Systems* (Cheltenham: Edward Elgar, 2006).
Gell-Mann, M., *The Quark and the Jaguar* (New York: W. H. Freeman, 1994).
Gladwell, M., *The Tipping Point* (London: Little, Brown and Company, 2000).

Gleick, J., *Chaos* (London: Abacus, 1987).
Golding, W., *Lord of the Flies* (London: Faber & Faber, 1954), 1996 reprint.
Goodwin, B., *How the Leopard Changed Its Spots* (London: Weidenfeld and Nicholson, 1994).
Gould, S. J., 'Punctuated Equilibrium in Fact and Theory', *Journal of Social Biological Structure*, 12 (1989) 117–136.
Haken, H., *Synergetics, an Introduction: Non-equilibrium Phase Transitions and Self-Organization in Physics, Chemistry and Biology* (Berlin: Springer-Verlag, 1977).
Hamel, G. and C. K. Prahalad, 'Strategic Intent', *Harvard Business Review*, 67, 3 (1989) 63–76.
Holland, J. H., *Adaptation in Natural and Artificial Systems* (Ann Arbor, MI: University of Michigan Press, 1992).
James, W., *Selected Writings* (London: Everyman, 1995).
Kaufmann, S. A., *At Home in the Universe: The Search for the Laws of Self-Organization and Complexity* (New York: Oxford University Press, 1995).
Kay, J. and E. D. Schneider, 'Embracing Complexity, the Challenge of the Ecosystem Approach', *Alternatives* 20, 3 (1994) 32–38.
Lawrence, P. and J. Lorsch, *Organization and Environment* (Boston, MA: Harvard University Press, 1967).
Lewin, R., *Complexity* (London: Phoenix, 1995).
Lewin, A. Y. and H. W. Volberda, 'Prolegomena on Coevolution: A Framework for Research on Strategy and New Organizational Forms', *Organization Science*, 10, 5 (1999) 519–534.
Lewin, A. Y., C. P. Long and T. N. Carroll, 'The Coevolution of New Organizational Forms', *Organization Science*, 10, 5 (1999) 535–550.
Lorenz, E. N., 'Deterministic Nonperiodic Flow', *Journal of the Atmospheric Sciences* 20, 2 (1963) 130–141.
Lorig, K., R. Stewart, P. Ritter, D. Gonzalez, V. Laurent and D. Lynch, *Outcome Measures for Health Education and Other Health Care Interventions* (London: Sage, 1996).
Lovelock, J., *The Revenge of Gaia* (London: Penguin Allen Lane, 2006).
Maguire, S. and B. McKelvey, 'Complexity and Management; Moving from Fad to Firm Foundations', *Emergence: A Journal of Complexity Issues in Organizations and Management*, 1, 2 (1999) 19–61
Mandelbrot, B., *Fractals – Form, Chance And Dimension* (San Francisco, CA: W. H. Freeman, 1977).
Maturana, H. and F. J. Varela, *The Tree of Knowledge* (Boston, MA: Shambhala, 1987).
McMillan, E., *Complexity, Organizations and Change* (London and New York: Routledge, 2004)
Middleton-Kelly, E., 'Ten Principles of Complexity and Enabling Infrastructures'. In E. Middleton-Kelly (ed) *Complex Systems and Evolutionary Perspectives on Organisations: The Application of Complexity Theory to Organisations* (London: Elsevier, 2003)
Miller, D., *Strategy Making in Context: Ten Empirical Archetypes* (PhD thesis) (Montreal: Faculty of Management, McGill University, 1976).
Mintzberg, H., *The Strategy Safari* (Harlow: Financial Times/Prentice Hall, 2002).
Nicolis, G. and I. Prigogine, *Exploring Complexity: An Introduction* (New York: Freeman, 1989).
Peters, T. and R. H. Waterman, *In Search of Excellence: Lessons from America's Best-Run Companies* (London: Harper and Row, 1982).
Poincaré, H., 'Sur Le Problème Des Trois Corps Et Les Equations De La Dynamique', *Acta Mathematica*, 13 (1890) 1–270.
Pratt, J., P. Gordon and D. Plamping, *Working Whole Systems; Putting Theory into Practice in Organisations* (Oxford: Radcliffe Publishing Ltd, 2005).
Prigogine, I. and I. Stengers, *Order out of Chaos: Man's New Dialogue with Nature* (New York: Bantam, 1984).
Quinn, J. B., *Strategies for Change: Logical Incrementalism* (Homewood, IL: Richard D. Irwin, 1980).
Raup, D. M., *Extinction: Bad Genes or Bad Luck?* (London: W. W. Norton and Co., 1992).
Richardson, K., 'The Hegemony of the Physical Sciences: An Exploration in Complexity Thinking', *Futures*, 37 (20052) 615–653.
Rihani, S., *Complex Systems Theory and Development Practice* (London: Zed Books, 2002).
Snowden, D., 'Complex Acts of Knowing: Paradox and Descriptive Self-Awareness', *Journal of Knowledge Management*, 6, 2 (2002) 100–111.
Stacey, R. D., *Strategic Management and Organisational Dynamics: The Challenge of Complexity* (Harlow: Financial Times/Prentice Hall, 2003).
Stacey, R. D., D. Griffin and P. Shaw, *Complexity and Management: Fad or Radical Challenge to Systems Thinking?* (London: Routledge, 2002).
Streatfield, P., *The Paradox of Control in Organisations* (London: Routledge, 2001).
Teece, D. J., G. Pisano and A. Shuen, 'Dynamic Capabilities and Strategic Management', *Strategic Management Journal*, 18, 7 (1997) 509–533.
Thompson, J. D., *Organizations in Action* (New York: McGraw Hill, 1967).
Tirpack, D., 'Avoiding Dangerous Climate Change', *Scientific Symposium on Stabilisation of Greenhouse Gases*, February 1–3 (2006).

Ulanowicz, R. E., 'An Hypothesis on the Development of Natural Communities', *Journal of Theoretical Biology*, 85 (1980) 223–245.
von Bertalanffy, L., *General Systems Theory* (New York: Braziller, 1968).
Waldrop, M. M., *Complexity: The Emerging Science at the Edge of Order and Chaos* (Viking, 1992).
Weber, M., *Economy and Society* (Berkeley, CA: University of California Press, 1978).
Wheatley, M. J., *Leadership and the New Science* (San Francisco, CA: Berrett-Koehler, 1992).