Complexity Theory and Knowledge Management Application

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Abstract: This article traces the development of complexity theories and proposes a Complexity Representation Model (CRM) for management processes. The purpose here was to translate key elements of complexities theories (e.g. self organisation, adaption, co-evolution, chaos) into a recognisable form and relate these to management practice (particularly knowledge management and learning).

A further Complexity Application Model (CAM) is offered that shows the relationship between the formal and informal aspects of the management environment and the CRM. It models an active environment that should learn and adapt to minor perturbations and major schisms. It is a conceptual guide as to the "ideal" management system, one that self-organises, learns, adapts and evolves with its environment. The application of the CAM is discussed in terms of practical methods and processes that can be used to manage and encourage managers to feel they are in control of a complex adaptive management system.

Keywords: Complexity theory, complexity theories, complexity representation and application, knowledge, learning.

1. Introduction

Management has been an area of research interest for many years and currently there is a focus on whether management processes can be made adaptive and self-organising. The application of complexity theory to management seems to offer possible solutions to this aim. Complexity theories offer the distinct advantage over previous research that it is not reliant on retrospection nor is it contingent.

This article is based on the results of a Research Council funded applied research programme investigating complexity and how companies deal with it. It looks at complexity from a theoretical viewpoint and explains how the subject has developed. It then goes on to propose ways in which the theory might be applied in practice. It is only when the complexity theory is simplified and treated as a cultural/knowledge/learning process that any real application potential emerges. The management environment is an active one that changes with time. It is also a human system that should learn, adapt and evolve. Understanding the relationship between the whole system and its parts as it learns and adapts is vital.

Our CRM (Figure 1) translates the key elements of complexity theory into a recognisable form. We have extended this with our CAM (Figure 2) that shows the relationship between the formal and informal aspects of the management environment.

2. Management practice and complexity

2.1 Introduction

Complexity theory has grown out of systems theory and chaos theory in an attempt to demonstrate why the whole universe is greater than the sum of the parts and how all its components come together to produce overarching patterns as the system learns, evolves and adapts.

The Science of Complexity attempts to explain and simulate systems hither to unfathomable through previous modes of scientific thought. Indeed, scientific thinking has fundamentally shifted from the practices of the Scientific Revolution of Newton, Descartes and Galileo. Their models were mechanistic, study was restricted purely to measurable and quantifiable characteristics and the 'world as a machine' became the metaphor for the era. Here, all that happened had a definite cause and gave rise to a definite effect, thus making outcomes and relationships predictable. Scientific analysis was dominated by Descartes' reductionist approach which asserts that phenomena can only be understood by breaking them into increasingly smaller parts and only once the part properties are known can the whole be determined (Capra, 1996). Centuries later following a series of backlashes and resurgences of the mechanistic view, the paradigm has given way to the new sciences of 'complexity'.

Capra reviews the widely agreed view of systems thinkers (Checkland, (1991) and Bertalanffy, (1968). Their viewpoint contradicts the traditional reductionist thinking by asserting that:

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- A system is an integrated whole, whose properties cannot be reduced to the sum of its parts.
- All phenomena are interrelated yet independent thus each system forms part of a larger system, yet each has its own individual properties. This is the idea of systems being nested or arranged in a hierarchy.
- Each system exhibits properties that do not exist at lower levels within the hierarchy. These are called 'emergent properties' e.g. life, consciousness
- The observer influences the determination of the system boundary i.e. what is be described as part of the system and what is excluded and the purpose of the system thus making definition of the system and its constituent parts critical.
- Systems are subject to feedback i.e. the influence of one element on another within the system. The nature of this feedback can vary either being positive (amplifying and providing 'gain' in the system) or be negative (declining, 'damping' of the system). This is so called 'non-linear' behaviour.

Chaos theory relates to this latter point that systems behave in a non-linear fashion particularly that small changes in initial conditions can have a large impact on outcomes. Rosenhead (1998) highlights that chaotic systems do not exhibit pure random behaviour as common use of the term 'chaos' might suggest. These systems are neither stable nor unstable; rather they operate at a boundary between the two zones in what has been termed 'the edge of chaos'. It refers to systems that display behaviour that, though it has certain regularities, defies prediction.

Complexity theory incorporates previous theories of chaos and systems extending this list of systems attributes and explores the behaviour of systems that show the ability to adapt and evolve over time.

2.2 Defining complexity

It may seem a tautology to describe complexity as "complex"; however, this is the very problem at the heart of its definition and application. Indeed, the underlying view of the early studies of complexity carried out by pioneers and populists of complexity from the Sante Fe Institute (Waldrop (1992), Casti (1994), Gell-Mann (1994)), was that the subject was so new and wide ranging that nobody knew quite how to define it, or even where its boundaries lay

> *'Probably no single concept of complexity can adequately capture our intuitive notions of what the word ought to mean. Several different kinds of complexity may have to be defined, some of which may not have been conceived; 'every definition of complexity is context dependent even subjective.*' (Gell-Mann (1994)).

> *'Complexity is a multi-dimensional, multidisciplinary concept. (There is) No one right way to define and measure it'* (Smarr in Corning (1995)).

Corning (1995), Horgan (1995) and Edmonds (1997) have all identified a wide range of definitions of complexity e.g. abstract computational complexity, Kolmogorov complexity, arithmetic complexity, cognitive complexity, horn complexity etc. Horgan (1995) identified 31 definitions of complexity and accused the scientific community of a lack of cohesion and unified theory. The concept has remained open to interpretation and a burgeoning number of studies have ensued across a range of disciplines particularly in the USA and Europe.

Over the past 30 years, the work of the Sante Fe Institute (particularly Kaufmann (1993)) and others have shaped our under standing of complexity. There is now an extensive and rapidly growing body of literature that examines the characteristics of complex systems and complexity theories (Waldrop (1992), Casti (1996), Kauffmann (1993), Gell-Mann (1994), Lewin (1993), Capra (1996), Flake (1998)). The three "leading" researchers on relevant complexity theory we have found are:

Sante Fe Institute: Complex Adaptive Systems (CAS) is the term used by the Sante Fe Institute to describe a system that adapts through a process of 'self organisation' and selection into coherent new behaviours, structures and patterns. The Sante Fe Institute of Complexity can lay reasonable claim to having "discovered" complexity. It certainly developed the initial framework from which most other research evolved. It is from this premise and basic work that the two other major contributors in this area started their work.

Mitleton-Kelly (2003): Uses the term Complex Evolving Systems (CES) and drew together much of the research work. This study has built up an understanding of the theories that relate to CES. The work combines the findings from natural and social science. The rationalisation of the literature focuses on the characteristics of so called CES (termed to differentiate it from the Sante Fe Institute terminology).

Holbrook (2003): Describes these phenomena as Dynamic Open Complex Adaptive Systems (DOCAS) and consolidated prior work. Holbrook's review identified the characteristics of DOCAS, covering many of the definitions offered by Mitleton-Kelly. In summary, these are:

- Interaction and feedback effects through networks
- Sensitive dependence on initial conditions
- Unpredictability of outcomes
- Dissipative structures and self-organised criticality
- Adaptive evolution and natural selection
- Hierarchically nested levels
- Co-evolution
- Simple rules and complex behaviour

"Complexity as Complex Adaptive Systems is the single most-important idea in all of chaos and complexity theory" (Holbrook (2003)). Theories of CAS, DOCAS etc. have shown insights when applied to real-world systems including weather, ant colonies, evolutionary biology and business in the process of adaptation and survival (Holbrook).

2.3 A complexity representation model

Our aim was to try to make sense of all this theory and produce practical application outputs. As a starting point we reviewed all the theories and grouped the complexity characteristics found in all this work.

Table 1: Complexity characteristics by group

Organisation:	Self-organisation of structures (relationships) and rules for interaction
	The ability to innovate
Interactions:	Agent-driven interactions
	Interchanges with external environments
	Distribution of information process and problem solving
Random events	Instability (never really at equilibrium)
	Perturbation i.e. unplanned/unpredictable events (internal/external origin)
	Non-linearity: the conditions that small events may have no effect, or may create an avalanche of change
Adaptation:	To changing environments
Evolution:	Occurrence of events altering the course of evolution: 'frozen history'
	Emergent phenomena
	The existence of memory/ expectations/predictions
	Sustained co-evolution

We have chosen this grouping as the relationship to management may be seen and we have shown this diagrammatically in Figure 1.

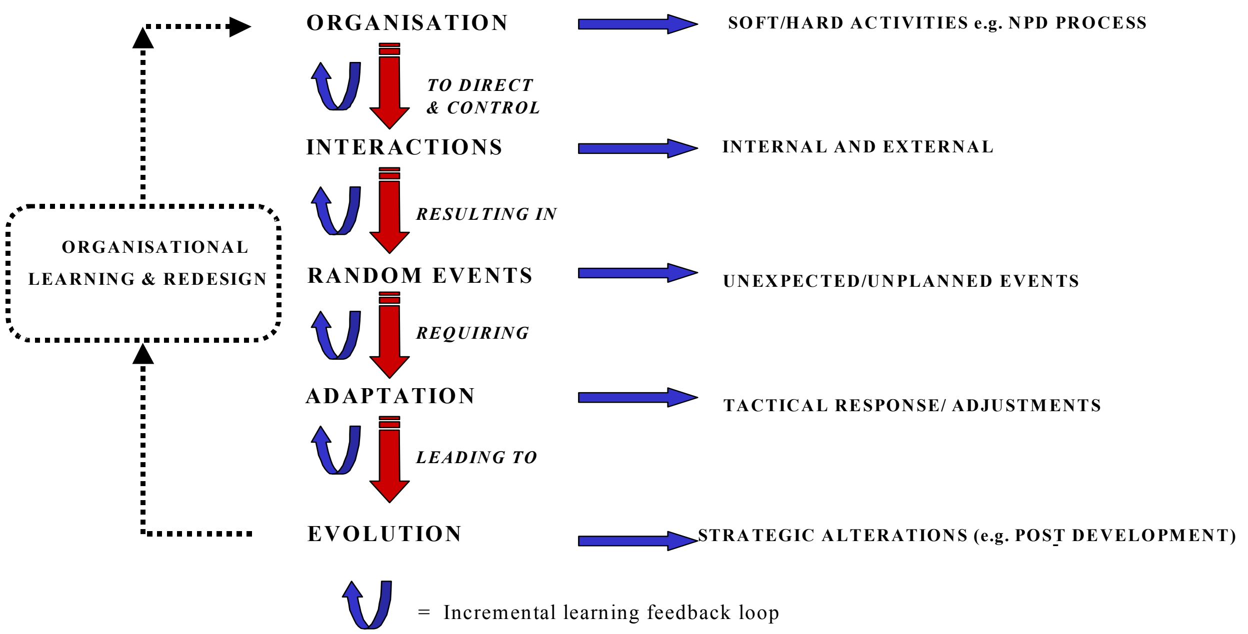

Figure 1: Complexity representation model Management processes

By the phrase "management processes" we mean the basic, generic processes relating to management in general. Rather than adopt a functional or activity based approach, we attempted to deal with management processes holistically. This proved difficult to do, as most published literature is contingent. In the end we chose to use two key aspects of management and management development:

- Knowledge accumulation and dissemination
- Learning capability and application

2.4 Knowledge accumulation and dissemination

In essence, management can be said to be based on the gathering and transforming knowledge into marketable products and services. Thus the management of this knowledge collection and transformation is critical to success. A good starting point for the exploration of this area is Wiig's (1995) three-volume discourse "Knowledge Management Methods". Of especial interest to us was the first volume describing the way in which people and organisations create, represent, disseminate and use knowledge. Wiig argues that it is essential that the key knowledge domains are identified and incorporated within the organisation's activities and structures. Wiig defines this as the concept of Critical Knowledge Function (CKF) and goes on to describe various CKFs such as Business, Constraints, Vulnerabilities, Opportunities etc.

Wiig describes this panoply of CKFs as "multiple CKFs" leading to complexity escalation, causing problems in the management and organisation of people and activities in order to extract maximum value from the knowledge base. The problem of identifying the key areas of knowledge conversion and dissemination has also been addressed by Hall and Andriani (1998) in their knowledge capability framework.

This escalation of internal complexity is extended with external influences. Markets shift, uncertainty dominates, technologies proliferate, competition multiplies and products and services have shorter life cycles. Thus knowledge management becomes key to organisational development, learning and innovation (McElroy (2003)). At the heart of this organisational development is the relationship between tacit knowledge (informal), which is held within individuals and explicit knowledge (formal), which is articulated, codified and distributed (Davenport & Prusak (2000), Nonaka & Takuechi (1995)). Knowledge creation, dissemination and use within an organisation are dependent on the conversion of tacit to explicit knowledge. Nonaka and Takuechi (1995) propose four ways in which this happens:

- Socialisation (tacit to tacit)
- Externalisation (tacit to explicit)
- Internalisation (explicit to tacit)
- Combination (explicit to explicit).

Whilst technology plays a role in this conversion (e.g. use of an Intranet system), it is essentially a human based process.

Von Krogh et al (2000) argue that knowledge exchange and development is best achieved formally through clear organisational goals. In contrast Sainte-Onge and Wallace (2003) assert that this conversion issue is best addressed informally through human processes with groups of like-minded individuals coming together in Communities of Practice (CoP) to share knowledge. It is this informal aspect that we have tried to develop within our complexity model (see later). As if ensuring that the organisation "knows what it knows" is not complex enough, defining what it "needs to know but does not know" adds yet another layer of complexity. Koulopoulos (1997) proposes the concept of knowledge gaps, which can be evaluated by using the "knowledge chain" comprising:

- Internal awareness leading to
- Internal responsiveness
- External awareness leading to
- External responsiveness.

Again there is both a formal (e.g. patent searching) and informal (e.g. networking) elements to this problem. What is essential in either case is the ability for the organisation/individuals to learn, develop and adapt.

Within organisations there are critical knowledge functions, with people accumulating (from internal and external sources), converting and disseminating knowledge for practical application. Some of this is achieved through formal systems, but the scale and complexity of the processes means that much of this is achieved through informal processes such as CoPs. It is the combination of formal and informal (based on complexity theory) organisational structures and systems that is critical. This provides the balance between freedom and control required within a commercial operation. The informal aspects are too important to be left to chance and need to be encouraged and "incorporated" into formal organisational processes.

2.5 Development of learning capability

The abilities to learn, self-organise and adapt are key elements of complexity theories and, if handled appropriately, should aid management practitioners. Business has entered the knowledge era where information is power and learning rapidly and competently is a necessary condition for success. The need for this approach was identified by Marquardt and Reynolds as early as 1994. Keirman (in Schwandt and Maquardt (2000)) argues, "Learning will become the only viable alternative to corporate extinction".

In 1978, Argyris and Schon suggested that organisational learning is the process by which organisational members detect errors and correct them by restructuring the organisational theories in use. Later, Argyris (1999) confirmed this idea of error-based learning when organisational intentions are not met (mismatched). However, he extended this to learning when organisational intentions are met (matched) i.e. learning from getting things right. These ideas align with the notion that structural capacity to learn corresponds to the characteristics of an organisation that favours individual and collective learning (Finger and Brand (1999)). Thus the nature of learning is influenced by the organisation's structure and its communication practices and affects business process such as product innovation (Ayas (1999)).

Calantone et al (2002) reported that a learning orientation has an affect on a firm's innovativeness, which in turn influences performance. In their study, the higher-order construct of learning orientation comprises of four components: i.e. learning, shared vision, open-mindedness and inter-organisational knowledge sharing. All these ideas were to a large extent pre-empted by McKee (1992) who related innovations in general to organisational learning and proposed three levels:

- Single loop learning associated with incremental product innovation
- Double loop learning associated with discontinuous product innovation
- Meta learning associated with institutionalising innovation within organisations.

All this work has direct relevance to management processes and their management depending on the nature of the product innovation that is taking place.

In summary, it can be seen that individual and organisational learning is now a key factor in any commercial organisation. Whether from mistakes (mismatches) or by getting things right (matches), learning is critical. The nature of learning and its degree of contribution are influenced by the organisation's structure, culture and communications practices. The key success elements success appear to be:

- Learning orientation
- Shared vision
- Open-mindedness
- Inter-organisational knowledge sharing

McKees' work suggests that this learning process may be applied at both simple and complex (meta) levels. It is this work that we will carry forward into the discussion of complexity and its application.

3. Complexity theories and management

3.1 An overview

If we start with the knowledge aspect of our complexity representation model (Figure 1), it is the nature of the Organisation and its interactions that allows knowledge to be created and/or gathered and distributed for use. The critical knowledge functions are known and are catered for by the company's formal systems, usually on past experience. However, because of the scale and complexity of the processes, unpredicted Random Events will occur highlighting knowledge gaps. It is here that the informal processes are needed with people accumulating converting and disseminating knowledge via the informal activities such as CoPs.

Companies must accept that they cannot plan for every eventuality. Most of the management practitioners involved in our research programme adopted a "plan as much as you can, get on with it and then fire fight!". In this context, "fire fighting" was viewed as an unavoidable activity. This approach provides the balance between control and freedom required within a commercial operation. By encouraging informal processes (CoPs etc.) a company develops an informal knowledge generation capability. This can be used to address minor perturbations without distracting the whole process. If major disruptions occur, then the work of the CoPs can be brought within the formal system.

In terms of learning, the organisation learns and develops in two ways:

- Incremental: Small adjustments that overcome small perturbations and keep the management process on track e.g. product development process.
- Comprehensive: Major organisational redesign, usually following a review e.g. a post development review

Applying this to product innovation, it is clear that such a process will be influenced by the organisation's structure and its communication practices. The key elements for success appear to be shared vision, open-mindedness (especially in management) and inter-organisational knowledge sharing which are key elements of CoPs. McKees' work accords with the knowledge aspects of our complexity representation model in that the learning process is applied at both simple (incremental) and complex (meta or comprehensive) levels. Again there is a balance between formal learning (e.g. corporate intranet systems allowing the exchange of ideas and experiences to take place) and informal learning through CoPs etc.

3.2 Complexity application model

We have taken our complexity representation model and combined it with the work on knowledge, learning and formal/informal processes to produce a Complexity Application Model (CAM) as shown in Figure 2.

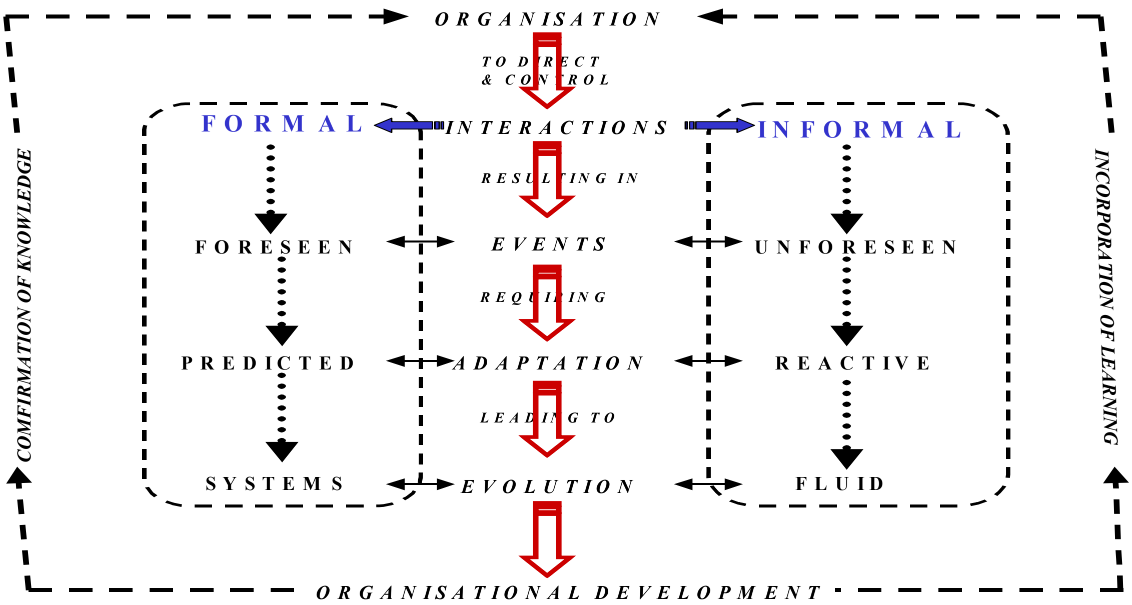

Figure 2: Complexity application model

The CAM uses as its basis the complexity theory "flow" from Organisation to Evolution.
* *Complexity theory basis:* This is the central flow from Organisation to Evolution. This interacts with the organisation's formal and informal systems and processes.

Formal aspects: The left-hand side "box" represents the organisation's formal knowledge, processes, systems and procedures that deal with foreseen/predicted potential events through contingency planning and systems. Here potential "mismatches" are predicted and the capability to deal with them should, they arise, is built into the systems. These formal processes remain valid until a serious "mismatch" occurs that demands significant changes. These may be dealt with as a development proceeds but especially during post development review.

Informal aspects: The right-hand side "box" represents the organisation's informal knowledge and learning processes etc. that deal with unforeseen events through the capability of the organisation's people and culture. Here "mismatches" are unpredicted and are dealt with through complexity theory based learning, adaptation and evolution. Minor "mismatches" can be dealt with by the informal systems (CoPs etc) without recourse to changes in the formal system. Where the "mismatch" is serious, the results of the informal system's action can be incorporated into the formal processes.

Confirmation of knowledge: This has two dimensions. If the events "match" requirements and/or predictions, then the existing knowledge is valid and is confirmed. If events create a "mismatch" then the new, appropriate knowledge has to be incorporated, validated and confirmed. In either case, new learning may be absorbed.

Incorporation of learning: Again, this has two dimensions. Whether events "match" or "mismatch" new and appropriate learning may be incorporated into the organisation as required for improvement.

Organisational development: Here there are two extremes. If the formal processes work well, then the organisation's knowledge base is confirmed as being correct (i.e. matches). Minor perturbations are addressed by the informal systems that are capable of dealing with them. If the formal processes do not work well enough (mismatches), then the learning from the informal processes may be built into the formal processes. E.g. For New Product Development, a post development review

(PDR) is typically a key element in this. Clearly, a company need not wait until PDR to transfer any learning into its formal processes.

It is the informal aspects of the model that exhibit the basics of complexity theory. This model is, in effect, a system that adapts through a process of ‘self organisation’ and selection into coherent new behaviours, structures and patterns.

4. The complexity application model in practice

4.1 Formal v. informal processes

In terms of the formal aspects of the CAM, there has been an immense amount of work published on management processes, procedures, systems and activities models. These models are widely used and are useful for general representation, control and evaluation but suffer from two major problems:

- They are static and do not change as circumstances change
- They are out of date almost before they are published

This is the formal (left-hand “box”) aspects of the CAM and will not be dealt with here save to say that most organisations find them useful. What we are interested in is how the right-hand side of the CAM, the informal and complexity-based activities can be promoted and realised. We propose the following:

4.2 The CAM as a conceptual framework

General: The CAM is a good conceptual model for the overall environment. It demonstrates both the formal and informal activities and processes that are essential for success. More importantly, it demonstrates the importance of the informal processes to success, something that is generally overlooked by organisations (see later). The CAM may used to reinforce the importance and use of controlled processes, procedures and systems whilst also addressing the fact that “fire fighting” is an essential activity. This leads to:

Acceptance: By accepting the latter fact (that not everything can be predicted and controlled formally) plans can be made to put in place the alternative (informal) methods that are needed for resolution of many of the random events that will occur. This in turn demands a:

Culture: Of knowledge sharing, learning and open-mindedness with a shared vision. This is critical for an organisation to “self-evolve” within the complexity framework.

4.3 The CAM applied in practice

Strategic development: This may be enhanced by the organisation addressing and utilising the complexity aspects of the CAM to advantage.

Balance: Between formal and informal systems is critical and the organisation needs to learn to develop the ability to rapidly incorporate informal learning into the formal processes.

People: Well trained and informed people who are capable of extending their job roles to deal with unexpected events themselves.

Informal groups: Encouraged to form out of mutual interests and benefits (e.g. CoPs).

Management: That is more facilitating than directing, supportive than accusative and open than closed.

Informality absorption: There must be a process or processes that allow the informal knowledge and learning to be identified and absorbed into the organisation as needed. It is impossible to give definitive answers to this but they would include: open door policies, “formalising” informality through key team members, open intranet, identification of opinion leaders etc.

All these criteria are easy to define but more difficult to realise without recognising that it is people that are the key. The need for well-trained, informed people is understood by most organisations but often this is limited to their technical capabilities. If complexity theory teaches us anything, it is that the non-technical aspects that bring about the process of “self organisation” and new behaviours, structures and patterns that is critical. These non-technical issues need to be addressed at individual and group level.

To our mind, it is the encouragement of the concept of informal groups especially CoPs that can be the driving force in the successful application of complexity theory based activities. To allow CoPs to flourish, the people in them must be trained and capable and the management must be comfortable with the informal processes and what they are trying to do. This is where balance comes in. In a truly complexity based system there would be no direction and control but this is unlikely to be the case in practice. Thus a CoPs type system will involve some control and direction. It will also need some “formal” system to allow its output to be utilised by the wider organisation. In essence, the CoPs should be a formal, informal team with all the attributes and skills of a good team.

5. General discussion

This article has traced the development of complexity theory and to say that complexity is complex is somewhat of an understatement. At least 31 different kinds of complexity have been defined with every definition of complexity being context dependent, even subjective. As complexity has emerged as a subject, and become better understood, it is natural that attempts should be made to apply it to the management environment. The positive aspect of this attempted application of true complexity theory (not simplification etc) to management is that in almost every theoretical work, there is at least an intuitive relationship.

This affinity of complexity with management processes intuitively leads one to the idea that if complexity theory could be related to them, then gains should be made in improved performance and success rate. However, actually achieving this application relationship has proved to be difficult. At the heart of this problem is the fact that application models of management systems and their environments tend to be static. The actual management environment evolves (incrementally or in a wholesale way) and the models do not.

It is only when the complexity theory is simplified and treated as a cultural/knowledge/learning process that any real application representation emerges. In our opinion, it is the evolutionary aspect of complexity theory that offers the best way forward for its application. The management environment is an active one that must change as a development proceeds. It is also a human system that should learn, adapt and evolve. Understanding the relationship between the whole system and its parts as it learns and adapts is vital.

Our Complexity Application Model (Figure 2) shows the relationship between the formal and informal aspects of Management. It represents the whole environment from strategic to tactical, from organisational to individual, from incremental adaptation to large-scale changes etc. It models an active environment that should learn and adapt to minor perturbations and major schisms. The model is a conceptual guide as to the “ideal” system, one that self-organises, learns, adapts and evolves with its environment. Whether this ideal state is actually attainable is discussed further in the conclusions.

6. Conclusions

Complexity theories offer the distinct advantage over previous research that it is not reliant on retrospection nor is it contingent. If the current performance state and future need can be defined, then a truly complexity based system should automatically adapt itself to the new need. We believe that our Complexity Application Model as a knowledge, learning and organisational development domain offers real insights into management at all levels. It forms the basis of the “ideal” management, one that self-organises, learns, adapts and evolves with its environment. Theoretically, this type of system is self-governing.

Perhaps the major potential stumbling block in all this euphoria is the actual Manager. Managers need to feel that they are in control. For this, they need systems and measurements that describe to them the current state of a development. Complexity theory argues that this is against the premise of complexity thinking since order should emerge from chaos. The idea of a Manager letting a system self-evolve and self-organise appears to be a difficult concept for organisations to accept. If complexity theory is to have a significant, practical impact then there clearly has to be a compromise between self-organisation/evolution and management control. The way to do this may well be as follows:

- Extract the key aspects of complexity theories that are clearly relevant to management.
- Map these onto the environment and practices as a systems approach (Figure 2).
- Produce relevant complexity based processes to incorporate the informal aspects of the organisation including knowledge and learning systems and methods.
- Relate these informal systems to the systems in operation.
- Institute an organisational development programme for new development programmes.

As management is a human system, the basis of all this has to be well trained and informed people operating in an open and trusting environment. It is probably unrealistic to envisage a management system that is truly self-organising and evolving and that needs no management. However, the complexity theory approach may well be able to define the basic needs of the system that will allow managed evolution to be carried out far more easily and successfully.

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