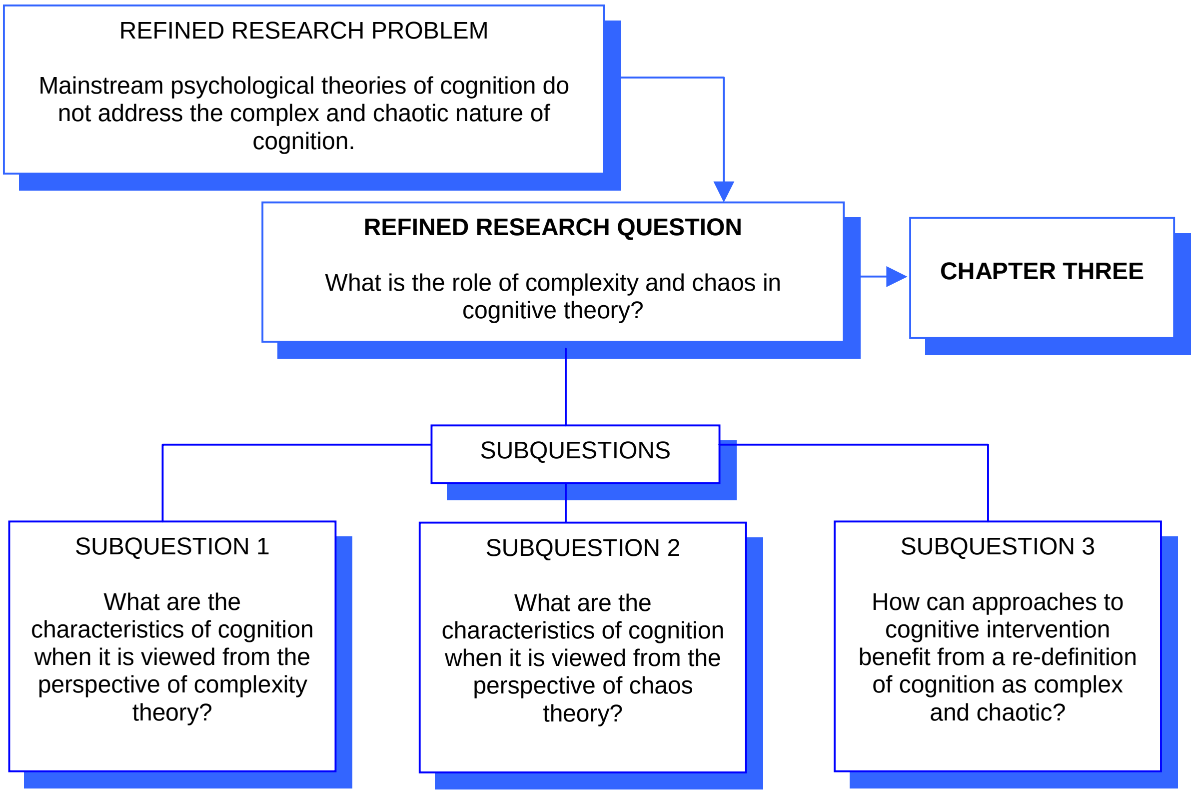
CHAPTER THREE

Accommodating principles of complexity and chaos in cognitive theory

> Chaos is not just one direction that we may stray too far toward. It is all around us and partly within us.
>
> Mahoney and Moes, *Complexity and Psychotherapy*

META-NARRATIVE 3.1



REFINED RESEARCH PROBLEM

Mainstream psychological theories of cognition do not address the complex and chaotic nature of cognition.

REFINED RESEARCH QUESTION

What is the role of complexity and chaos in cognitive theory?

CHAPTER THREE

SUBQUESTIONS

SUBQUESTION 1

What are the characteristics of cognition when it is viewed from the perspective of complexity theory?

SUBQUESTION 2

What are the characteristics of cognition when it is viewed from the perspective of chaos theory?

SUBQUESTION 3

How can approaches to cognitive intervention benefit from a re-definition of cognition as complex and chaotic?

3.1 INTRODUCTION

In the previous chapter I discussed how the discipline of psychology and the study of cognition were shaped by changing paradigms in the physical sciences. It appears that philosophers and psychologists have predominantly taken their cue from mathematicians, biologists and physicists. Whether it was to agree with them, or to oppose their ideas, philosophers and psychologists have looked to discoveries in the physical sciences for many of their questions and their answers.

For example, Barrow (1999) relates how the discovery of Euclidian geometry[15] (3 B.C.) established a style of reasoning that was characterised by the application of definite rules of reasoning from a collection of self-evident axioms, and how theologians and philosophers imitated this method of reasoning in their speculations. With Euclidean geometry, it was possible to establish absolute truths, and it was believed that Euclidean geometry described the world as it was. Euclidean geometry occupied the same position of authority then that Newton's classical physics enjoyed approximately a century and a half later.

However, when mathematicians discovered other geometries (hyperbolic and spherical)[16], each with its own set of logically self-consistent rules, it was apparent that Euclidean geometry was only one of many logical systems, and none could lay claim to the status of absolute truth (Barrow, 1999). Nonetheless, many philosophers still adopted the style of reasoning that Euclidean geometry established because it provided structure and credence to their arguments. Some philosophers, like Spinoza, exponent of the rationalist philosophy (Delius *et al.,* 2000), even laid out their arguments "like the definitions, axioms, theorems, and proofs in Euclid's works" (Barrow, 1999, p. 42).

This chapter continues the discussion of the third period in the sciences in more depth in order to continue the discussion on how psychology and the physical sciences have converged at a point where both disciplines acknowledge the inevitable complexity of their subject. I will reflect on the possibility that the postmodern period in science and psychology offers a promising new direction for cognitive research, and indeed psychology generally (Mahoney & Moes, 1997), since postmodern theory appears especially able to address the complexities of human cognition.

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[15] Euclidean geometry deals with the measurement of flat spaces.
[16] Hyperbolic and spherical geometry deals with the measurement of curved spaces.

However, a note of caution is in order. Just as it is possible to live in a world where the principles of classical physics and modern physics both hold under different conditions, so it is possible to live in a world in which human cognition can be conceived of as being both linear and unpredictable, depending on the conditions under which it is studied. If quantum theory has taught us anything, it is that cognition is a 'potential' phenomenon, not an 'actual' one. Cognition does not exist exclusively in one form or another. By this we mean cognition is not seated either in the mind, or in social experience. Rather, cognition is a collection of possibilities and probabilities, some of which are realised when we observe them in a particular way. Depending on how we structure our observations, cognition may be actualised in a number of different ways.

In this case, Heisenberg's uncertainty principle is particularly relevant to the study of cognition. If we structure our observations in order to measure the neuronal activity in the brain, we lose sight of the complex interactions between different structures of the brain, and we gain little knowledge of social aspects of problem solving. When we focus our attention on the role of perception in thinking, we tend to lose sight of the creative aspects of thought. If we study thinking in groups, we are inevitably unable to focus simultaneously on what happens in the brain.

META-NARRATIVE 3.2

My aim in this study is not to discredit current theories of cognition. Rather, I wish to reflect on the limitations within which current theories of cognition operate. It has been pointed out repeatedly that cognitive research is fragmented and lacks coherency (Vosniadou, 1997; Newsome, 2000) and I believe this may be the result of our failure to commit ourselves as scientists, to building an integrated picture of human development. There is too much focus on theoretical differences and too much interest in advancing one particular theory over another. Perhaps it could be fruitful to cognitive theory development in general if one were to consider adding a basic feature of cognition that is not being addressed adequately in mainstream cognitive psychology. The dimension I am referring to is *chaos*, believed to be the essence of complex systems.

In this chapter, I will explore two theories considered to be relevant to an investigation of cognition within a postmodern context, namely complexity theory and chaos theory. Finally, I will examine some of the implications that complexity theory and chaos theory might hold for cognitive intervention in a postmodern context.

3.2 PSYCHOLOGY, COMPLEXITY AND CHAOS

3.2.1 Complexity and chaos in psychology

At the beginning of the twenty-first century, the symbiotic relationship between psychology and the physical sciences continues its existing trend. Mahoney and Moes (1997) remark that

> It is interesting, if not ironic, that formal studies of chaos and complexity began in areas far removed from human systems and human affairs. The historical classics in these studies have originated in the areas of mathematics, physics, biology, and meteorology. This is not to say that there were no precedents in philosophy or the social sciences, but only that the vast majority of formal inquiries into "chaotics", complexity and spontaneous self-organization has [sic] been in the physical and biological sciences. With few exceptions, this remains the case today (p. 182).

Of course, this is not to suggest that mathematicians and physicists recognised complexity in human nature when psychologists would not. Even the very earliest students of human behaviour would readily have acknowledged the complexity of their subject. Speaking of the relevance of chaos theory to applied psychology, Perna and Masterpasqua (1997) point out that

> This new paradigm from the physical sciences…resonates more closely with the vagaries of human development and the therapeutic experiences that are so much a part of the everyday life of practicing psychologists. In this sense, these discoveries from the physical and natural sciences have caught up with the tacit acceptance, especially among practicing psychologists, that ours is a science of qualities rather than of quantities that must include an acceptance of unpredictability and free will (p. 5).

Yet Goertzel (1993) believes that contemporary psychology simply lacks the tools to confront comprehensive questions about the nature of mind and behaviour:

> Psychologists tend to become annoyed when their discipline is compared unfavourably with physics – and indeed, the comparison is unfair. Experimental physicists have many advantages over experimental psychologists. But the facts cannot be ignored. Physics talks about the properties of baseballs, semiconductors and solar systems, but also about the fundamental nature of matter and space, and about the origin of the cosmos. The physics of baseball is much more closely connected to experimental data than is the physics of the first three minutes after the Big Bang – *but there is a continuum of theory between these two extremes, bound together by a common philosophy and a common set of tools…*It seems to me that the key to understanding the mind lies not in contemporary psychology, but rather in a newly emerging field which I will call – for lack of a better name – "complex systems science." (p.2, own emphasis)

Despite Goertzel's (1993) doubts about the ability of contemporary psychology to confront the complexity of the human mind, developments in complexity and chaos theory over the past thirty years are generally thought to be of significant relevance to the science of psychology.

In applied psychology, psychotherapists especially are greatly inspired by the possibilities which chaos theory as a conceptual framework presents to psychology. For example, Lewis and Junyk (1997) suggest that chaos theory offers a plausible alternative to personality functioning as a causal, linear process. Lewis and Junyk (1997) describe personality functioning as a behavioural system that includes both predictability and uncertainty and describes personality self-organisation as "the emergence and crystallization of interpretive attractors over developmental time (or macro development)" (p. 50). Other applied areas of psychology in which chaos theory has found application include the study of *regression* (Perna, 1997), *dissociative disorders* (Derrickson-Kossmann & Drinkard, 1997), and *childhood trauma* (Lasser & Bathory, 1997). Finally, Masterpasqua & Perna (1997) comment that the sciences of chaos and complexity offer new models and metaphors from which to construct an understanding of the postmodern self.

This study is concerned mainly with human cognition, and it is the complex nature of thinking that is of particular interest. Although some texts briefly mention the relevance of chaos theory to the study of the brain (Groves & Rebec, 1992), the use of a conceptual framework that accommodates chaos and complexity in cognition is mostly restricted to mathematical psychology texts (Goertzel, 1993) and philosophical texts (Cilliers, 1998). A common phenomenon across all these texts, one that Lorenz (1993) acknowledged earlier, is that 'chaos' is often used synonymously with other terms such as 'non-linearity' or 'sensitive dependence'. Similarly, 'complexity' is often used to denote some form of chaos (Briggs & Peat, 1999).

Seeing that chaos and complexity can have such different meanings depending on the contexts in which they are used, it will be important to develop a clear description of what chaos and complexity might mean in the context of this investigation. The next section will briefly review the relevance of complexity and chaos to cognition, after which both theories will be discussed in greater detail.

3.2.2. Complexity and chaos in the study of cognition

Chapter Two started with a consideration of the meaning of complexity and the relevance of complexity to the study of cognition. I pointed out that our conception of complexity has evolved to acquire new meanings, and that this evolution was in large part due to evolving paradigms in the physical sciences.

I have begun to develop the notion of cognition as a complex phenomenon, and offered some preliminary ideas on what it might mean to speak of cognition as being complex. I have hinted at several concepts that are generally associated with complexity, namely chaos, sensitivity, dynamic interrelationships, and interconnectivity. However, what complicates matters considerably, is the fact that a term such as complexity is frequently used synonymously with chaos, as are terms like non-linearity and fractality (Lorenz, 1993).

In the next section, some of the central concepts in chaos theory will be developed by contemplating complexity within a postmodern context and relating the study of complexity to the study of cognition. The acknowledgement that one of the main characteristics of complex systems could be their chaotic nature, will inevitably lead us towards a consideration of some key features of chaos theory in Section 4.

3.3 COMPLEXITY THEORY AND COGNITION

3.3.1 Definitions of complexity

Defining complexity is a complex endeavour. Goertzel (1993) mentions that complexity does not mean ‘complicated’, but rather refers to structures that are diverse, intricate and in interaction, and have the capacity to organise themselves.

Lorenz (1993) states that complexity is often defined differently in different contexts. Consequently, the term may be used to indicate a system’s sensitive dependence on initial conditions, irregularity in space, or the length of a set of instructions that one would have to follow to depict or construct a system. The first two criteria are often used within the context of meteorology, while the last criterion is generally favoured by mathematical psychologists.

Cilliers (1998) says of complex systems, that they are not constituted merely by the sum of their components, but also by the intricate relationships between their components. Therefore, complexity is manifested at the level of the system itself. Luhmann (1985 in Cilliers, 1998) states that complexity means that there are more possibilities than can be actualised. In this regard, Cilliers (1998) agrees that complex systems contain such intricate sets of non-linear relationships and feedback loops that only certain aspects of the system can be analysed at a time, and even then such analyses will be characterised by distortions. Some of the complex systems that Cilliers (1998) identifies as complex, include mostly ‘living’ things such as bacteria, the brain, social systems and language.

Whether the mind is represented mathematically (Goertzel, 1993), or metaphorically (Perna & Masterpasqua, 1997), there is much evidence that suggests that cognition is a complex and chaotic phenomenon. In the next section, I will explore the complex nature of cognition by reviewing some characteristics of complex systems.

3.3.2 Complexity in a postmodern context

3.3.2.1 Objectivism and relativism

Cilliers (1998) contrasts modern and postmodern contexts by pointing out that modern approaches to complexity aspired to find a fixed point of reference that would serve as a foundation from which everything else could be derived, whereas postmodern theories highlight the open-endedness of phenomena. Earlier, Bernstein (1983) described the tension between modernism and postmodernism as one that involves an opposition between objectivism and relativism, or objectivity and subjectivity.

Perna and Masterpasqua (1997) assert that postmodernism challenges two fundamental modernist assumptions, namely that there is an objectively verifiable universe and that there is a self-contained, individuated self who can know the truth. Bernstein (1983) says that objectivism has frequently been associated with the claim that a world of objective reality exists independently of us and that what is “out there” (objective world) is independent of what is “in here” (subjective world). Bernstein (1983) contrasts such objective knowledge with a relativist position by saying that

> Relativism is the basic conviction that when we turn to the examination of those concepts that philosophers have taken to be the most fundamental – whether it is the concept of rationality, truth, reality, right, the good, or norms – we are forced to recognize that in the final analysis all such concepts must be understood as relative to a specific conceptual scheme, theoretical framework, paradigm, form of life, society, or culture (p. 8).

In Chapter Two we saw that the Heisenberg Uncertainty Principle and the Schrödinger wave function in quantum physics were largely responsible for stimulating the development of such relativist arguments in philosophical discourses on knowledge as proposed by Bernstein

(1983). However, the dichotomy between objectivism and relativism is not a twentieth century phenomenon. From the very beginnings of Western philosophy in 600 B.C., tension existed between the subjectivism and relativism of the Sophists, and the objectivism of Plato (Delius *et al.,* 2000). It continued throughout the Middle Ages which were characterised by the problem of universals. The problem of universals concerned itself with the question of whether general terms had any reality or whether they were simply constructs of thought and language (Delius *et al.,* 2000).

3.3.2.2. Complexity and relativity

There has been a tendency to describe postmodern theoretical developments as relativistic, a tendency which Cilliers (1998) dismisses as a sign of ignorance. Cilliers (1998) states that post-structuralism (deconstruction) is often (incorrectly) presented in anti-scientific terminology that stresses the proliferation of meaning, the shortcomings of logic and the breaking down of existing hierarchies.

Cilliers (1998) specifically takes issue with “over-zealous post-structuralists (especially literary theorists)” who should “transform their rhetoric into something cooler and clearer, something that can be argued with” (p. 22). Cilliers (1998) insists that post-structuralism is “not merely a subversive form of discourse analysis, but a style of thinking that is sensitive to the complexity of phenomena under consideration” (p. 22) and says that “post-structuralism has a more ‘playful’ approach” (p. 23). The playful approach that Cilliers (1998) argues for essentially refers to a recognition of the fact that most complex phenomena are open systems consisting of a multitude of possibilities which cannot possibly be known by controlling either the phenomena or the conditions under which they are studied.

As Perna and Masterpasqua (1997) rightly acknowledge, certain theories and discoveries in quantum physics had much to do with the introduction of the notion of openness and uncertainty in knowledge systems, although this is frequently not acknowledged in educational and philosophical discourses on postmodernism. In their discussion of the postmodernist self, Perna and Masterpasqua (1997) draw on concepts within complexity theory and chaos theory to describe the self as an open system, consisting of possibilities, sensitive to perturbations in the environment, and “always in a state of becoming” (p. 6).

This study aligns itself with Cilliers’ (1998) definition of postmodernism as one which recognises the complexity of phenomena, as well as the responsive and dynamic interaction of phenomena within various contexts in their environment. The relativism with which postmodernist approaches are associated at times is re-conceptualised within this study as an acknowledgement that complex systems are a collection of probabilities rather than actualities, and that it is impossible to know on an *a priori* basis which probabilities will be realised when the observer interacts with the system within a particular context and time frame.

However, at the moment when the complex system is being observed, some probabilities will indeed have crystalised within a particular context, and others will have collapsed. It is also recognised in this study that, contrary to relativist beliefs, some patterns of probabilities do in fact actualise with relative consistency across time and context. It is such consistency that gives rise to the emergence of a common human experience that allows the continuity in experience that makes it possible for humans to interact with one another meaningfully.

3.3.3 Universal features of complex systems and their relation to cognition

3.3.3.1 Open systems

Depending on the context, it is possible to generate different definitions of complexity. However, all complex systems display some characteristics that make it possible to classify them as being complex or not. Cilliers (1998) observes that, for the human mind and cognition to be considered as a complex system, it must be possible to show that they are *open systems* which interact with their environment and which can be modified by their environment.

There are various examples that show how the environment can modify the functioning of the brain. For example, the results of electrophysiological experiments with congenitally deaf people and normally hearing people show that left-right asymmetry in brain waves is present in normally hearing people, but not in congenitally deaf people for whom English is a second language after sign language. However, congenitally deaf people who are very skilled with English grammar do show left-right asymmetry in their brain waves. As a result, Groves and Rebec (1992) conclude that these experiments show convincingly that left hemisphere language specialisation may very well be a function of the early introduction of language, and that ”the early acquisition of grammatical competence in a language is both necessary and sufficient in the development of left hemisphere specialization for that language” (p. 488).

Moreover, studies on the environmental effects on the plasticity of the brain have thus far shown that the amount of visual stimulation that enters the eye strongly affects the structure and function of the visual cortex in the brain (Groves & Rebec, 1992). Studies on animals which had been raised in rich environments as opposed to animals which had been raised in isolated conditions, indicated that animals raised in rich and stimulating environments had heavier brains, the cerebral cortex was thicker and also contained higher levels of certain enzymes and other chemicals, and the neurons had formed greater numbers of branches, which were also longer than those of the control group (Groves and Rebec, 1992).

It appears as if the environment can even change the genetic blueprint that determines cell differentiation. For example, Purves and Lichtman (1985) in Groves and Rebec, (1992) have shown how a group of developing cells from one tissue change their pattern of development when they are transplanted within a new tissues. In addition, Pennington (1999) suggests that “subcortical structures which develop earlier, appear to be more strongly genetically influenced, whereas the cortex, which develops later, appears to be under both genetic and environmental influences” (p. 314).

The brain is therefore extremely flexible in its development, so flexible in fact, “that entire populations of developing cells may live or die depending on how they interact with other cells” (Groves and Rebec, 1992, p. 454).

3.3.3.2 Absence of equilibrium

Complex systems operate under conditions far from equilibrium. Briggs & Peat (2000) describe equilibrium as the maximum degrees of freedom of the system, which refers to the maximum amount of behaviours (an indication of chaos) that are available to the system. Masterpasqua (1997) claims that the concept of chaos indicates, in psychological terms, “a state of maximum readiness for an emerging reorganized self-system” (p. 37). Waldrop (1992 in Masterpasqua, 1997) describes the system as being in a state of perpetual novelty, life at the edge of chaos.

Cognition is not stable and unchanging, but actually thrives on ambiguity and change. People constantly review and change their thinking as a result of interaction with their environment. We recognise the complexity of a person’s conceptual structures by the diversity of their ideas and the richness of their thinking. Groves and Rebec (1992) quote various brain studies that convincingly show how complex experiences lead to increased complexity in brain structures and functioning, which in turn leads to increased complexity in behaviour. The implication is that complexity and unpredictability in the environment is necessary in order for complex cognition to emerge.

Clinical disorders which are associated with a disorder in thinking, such as mental retardation, may be associated with a loss of cognitive complexity, heightened levels of cognitive rigidity (perseveration) and reduced responsiveness to the environment. Also on a cellular level, mentally retarded children often show reduced dendritic growth, making the cerebral cortex appear more primitive (Groves & Rebec, 1992). On the other hand, psychotic disorders such as schizophrenia appear to be associated with higher levels of complexity as evidenced by increased chaotic functioning (Tschacher & Scheier, 1997). From these examples, it is important to note that complex cognition does not require constant chaos, but chaos is a necessary phase in the development of a system as it self-organises towards higher order.

3.3.3.3 Historical development

Complex systems have a history as they evolve over time, so it is critical to consider how their past influences the trajectory of the system over time. Complex systems theory emphasises the importance of gaining an understanding of the historical development of the system as a prerequisite for understanding the system's present behaviour.

On a physical level, the process of synaptogenesis provides compelling evidence that, as the brain evolves, its cognitive processes emerge and reveal increasing complexity. Most of the synapses in humans are formed over time and occur most prolifically in the first few years after birth. Groves and Rebec (1992) report that the nervous system continues to change and re-organise itself throughout the lifetime by re-arranging its synapses.

On a conceptual level, Piaget (Lerner, 2000) and Vygotsky (1935/1978)[17] both recognised the importance of studying the historical origins of thought in order to understand present thinking. Vygotsky (1935/1978) was adamant about studying the historical origin of an organism or function as opposed to merely describing its current appearance or function. The main reason for his position was that processes that appear to be the same on a descriptive level, may be qualitatively different when examined from a historical perspective.

3.3.3.4 Number of elements

Complex systems consist of a large number of *elements* that interact with each other on physical, as well as relational levels. It is critical to the understanding of a complex system to

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[17] This reference (and others to follow) refers to an unpublished manuscript originally written in Russian by Vygotsky in 1935, and published posthumously in 1978 in English.

note that individual elements of the system are considered to be ignorant of the behaviour of the system as a whole, so that the system is not centrally controlled. Rather, control is thought to arise out of the interplay of the agents (Waldrop, 1992 in Masterpasqua, 1997). In this respect, Cilliers (1998) reminds us that a large number of elements is a necessary, but not sufficient condition for complexity because it is really the dynamic interaction between the elements that is of interest.

Cognition is the result of the dynamic interaction of billions of elements on various levels. For example, on a physical level, Groves and Rebec (1992) estimate that the human brain has “well over ten billion nerve cells and probably more than ten times that number of glial cells.”(p. 42)[18] Cairns-Smith (2000) estimates that there may be about a hundred billion (10^{11}) neurons altogether in the human brain. On a social level, cognition emerges from complex interactions between language, culture and social interaction.

An indicator that is frequently used to distinguish between complex and complicated structure, is to see whether a structure lends itself to complete description. Whereas a computer can be described completely in terms of its components and programs, the brain cannot. Most living organisms are open and dynamic systems that do not lend themselves to complete description, which is why cognition, the brain, indeed the human body, can be thought of as a complex system.

3.3.3.5 Dynamic Interaction

The interaction between elements in the complex system is *rich*, with each element influencing and being influenced by a number of other elements. It is therefore critical to study complex systems as they occur naturally and to use experimental procedures that concentrate on historical development (Kellert, 1993 in Perna & Masterpasqua, 1997). Cognition arises from a rich interaction of various elements. Cairns-Smith (2000) says that the richness of the connections between neurons in the brain is evident from the fact that each brain cell is in touch with another through approximately six or seven intermediates, and that each neuron can have up to thousands of axons from other cells attached to it.

On a physiological level, learning and memory are believed to be linked to many cellular and subcellular processes, which “is greatly complicated by the large number of neurons and larger number of synapses that may be involved in even the simplest learning task” (Groves

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[18] Glial cells support nerve cells and cannot transmit information. Some glial cells form the myelin sheaths around neurons and others “clean up” neurotransmitters (Groves and Rebec, 1992; Cairns-Smith, 2000).

& Rebec, 1992, p. 513). On a structural level, Parkin (2001) reports that memory is associated with various structures in the brain's limbic system (hippocampus, thalamus, frontal lobe, amygdala and the lateral temporal lobe). Incidentally, these structures also play an important role in emotional behaviour (Groves & Rebec, 1992). Finally, Groves and Rebec (1992) conclude that "emotional behaviour is regulated by complex neural circuits, each one of which is modulated by other systems" (p. 408). Emotions play an important role in learning and memory because emotions, learning and memory processes all require some involvement of the same brain processes. In fact, particularly strong emotions can often make learning experiences more memorable and can have a decidedly positive or negative influence on a person's inclination to seek out certain learning experiences.

The interactions of various elements of the brain may even be responsible for the emergence of the mind. Nobel Prize winning physiologist, Roger Sperry, demonstrated convincingly in the early seventies that severance of the corpus callosum (which is responsible for relaying information between the hemispheres) effectively creates two independent minds. Sperry showed that individuals with split brains could learn a different task with each eye, independently of the other, without one hemisphere knowing what the other hemisphere was learning. This evidence leads Groves and Rebec (1992) to speculate that Sperry succeeded in dividing consciousness and the mind, a compelling demonstration "that the mind is an emergent property of the brain" (p. 495). Kak (1996) agrees when he remarks that "whereas the mind is emergent and based on the capabilities of neural hardware, it cannot exist without the universal self. One implication of these ideas is that machines, which are based on classical logic, can never be conscious." (p.189)

However, knowing that a complex system consists of a multitude of interactions among millions of elements is not enough to distinguish between systems that are complex and those that are complicated. Very sophisticated computers exist with many components and processes that could then equally well be regarded as complex. The main difference between a supercomputer and human cognition is to be found in the **nature** of the interactions between elements of the system. The interactions in complex systems are characterised by non-linearity.

3.3.3.6 Non-linearity

Non-linearity refers to the system's sensitive dependence on initial conditions (Lorenz, 1993). Sensitive dependence means that a relatively small change can lead to the system achieving end-states that show significant variance.

For example, various clinical disorders with dramatic behavioural and social implications often arise from small changes on a cellular and even subcellular level in the brain. Current research suggests that the difference between normal intellectual functioning and mental retardation may be associated with chromosomal errors (as in the case of trisomy-21), a change in the structure of neurons in the cerebral cortex, or specific conditions (e.g. nutritional factors) in prenatal and postnatal development. All of these changes occur on a small scale, but they lead to significant and dramatic variations in the ultimate behaviour of affected individuals.

As a system, cognition is very sensitive to initial conditions. The sensitivity arises from the non-linear interactions between the electrical, chemical, emotional, social and cultural dimensions of thinking. Schizophrenia for example, a debilitating condition characterised by a disruption of thought, emotional instability and psychotic episodes, is thought to arise from raised levels of dopamine in the brain. Moreover, the brain's apparent sensitivity to dopamine in such cases only occurs at the onset of adulthood after a period of apparent normal functioning, since the onset of schizophrenia is normally in early adulthood (Kaplan, Sadock & Grebb, 1991; Groves & Rebec, 1992). On the other hand, inadequate production of dopamine in certain areas of the brain is thought to lead to Parkinson's disease because the part of the brain (striatum) that controls the muscle actions required for complex voluntary movements does not receive enough dopamine from the substantia nigra, a group of neuronal cells that manufacture dopamine (Cairns-Smith, 2000).

Similarly, on a social interpersonal level, an event that may be construed as non-significant by one person, for example criticism from a significant other, may have a very significant impact on the thinking of the next person. For example, on an emotional level, attribution theory shows how people can feel very different emotions depending on their attributions of the outcomes of a situation to different antecedent causes (Byrnes, 2001). Emotional expression can also vary as a result of chemical interactions in the brain. For example, Groves and Rebec (1992) report on animal studies that suggest that predatory aggression in animals is associated with raised levels of serotonin, whereas aggression arising from irritation is associated with raised levels of norepinephrine. Similarly, Cairns-Smith (2000) reports that emotions can be severely disrupted if monoamine transmitter systems are interfered with.

3.3.3.7 Short range interaction

The interactions between elements in a complex system typically have a *short range* in the sense that they inform and transform their immediate environment, but not the behaviour of the system as a whole.

Cognition is characterised by many interactions that have the power to transform their immediate environment, but not the behaviour of the system as a whole. For example, Groves and Rebec (1992) point out that although the midbrain is responsible for the expression of aggression, the hypothalamus and amygdala play a mediatory role in the midbrain's response. On an even smaller scale, each synapse in the brain can only act on the next synapse with which it makes contact through chemical neurotransmitters, and billions of synaptic interactions and associations are necessary to produce certain patterns of behaviour. For example, Cairns-Smith (2000) says that spinal reflexes especially (like drawing one's hand away from a hot source), can be understood in terms of a subsystem that is connected by means of only a few neuronal cells.

On a structural level, electrical stimulation of certain parts of the brain show that certain functions are localised in particular areas of the brain (specialisation), and are not distributed throughout. For example, studies that use positron emission tomography (PET) and functional magnetic resonance imaging (fMRI), show increased blood flow and metabolic activity in the frontal lobe during a card sorting task (Groves & Rebec, 1992), while other areas of the brain show less activity. It is important to note in such cases that other brain regions are not completely inactive, but just show reduced metabolic activity.

Therefore, particular areas of the brain are responsible for particular cognitive behaviours associated with the activity in those particular regions, but one region alone cannot explain all dimensions of thinking. Moreover, even though certain brain areas are specialised for particular behaviours, those behaviours can be mediated by other areas in the brain. The point is that certain brain regions are responsible for particular functions, but no brain region has perfect knowledge of the total functioning of the brain. The concept of short range interaction therefore makes the emergence of cognition especially dependent on integrated functioning of the whole brain.

3.3.3.8 Feedback loops

In complex systems, a *feedback loop* exists in the interactions that allow the effects of any element to feed back into itself. Briggs and Peat (1999) distinguish between positive feedback loops that amplify a particular effect, and negative feedback loops that diminish some effects.

The existence of feedback loops is a central feature of cognition because feedback loops allow the dynamic, non-linear interactions between elements of cognition that may ultimately lead to the emergence of patterns associated with personality types, emotional styles, and cognitive dispositions. The importance of feedback loops therefore lies in the recognition that they can lead to stable patterns of behaviour around which a system organises itself. In this regard, positive feedback loops increase chaos in a system, negative feedback loops keep activity in a restricted range, i.e. reduce chaos in the system, and a coupling of positive and negative feedback loops creates a dynamic balance, also known as a bifurcation point, where chaotic activity is thought to branch off into order, i.e. a higher level of self-organisation (Briggs & Peat, 1999).

For example, Byrnes (2001) remarks that the so-called hemispheric asymmetry model of emotion suggests that the distribution of positive and negative emotions may be asymmetrically organised, leading to individuals developing various affective styles. Experiments by Davidson (1992, in Byrnes, 2001) in which EEG recordings taken from adults who were watching video clips designed to elicit either amusement or disgust were compared with video recordings of their facial expressions, indeed showed that 100% of the subjects had EEG activation patterns consistent with the notion that the left frontal region of the brain is specialised for approach (positive emotions such as happiness) and the right is specialised for withdrawal (negative emotions such as disgust). Other studies cited by Byrnes (2001) confirm the existence of stable patterns of reactivity in infants and college students, and which correlate with approach-avoidance behavioural strategies such as sociability and shyness.

Studies such as the aforementioned clearly point to the tendency of complex systems to self-organise and to develop adaptive (and maladaptive) patterns of behaviour. It may be possible that the mechanisms by which complex systems self-organise are governed by universal dynamic processes (positive and negative feedback loops) that lead to the development of certain patterns (also called attractors, which will be discussed in the next section) which may or may not lead to bifurcations in the development of the system.

I suggest that the universal features of complex systems may form the basis of the fundamental mechanisms which determine the emergence of human cognition.

3.3.4 Mechanisms of cognitive change

In the previous discussion, I reviewed some of the most important characteristics of complex systems. What has emerged from the discussion, is a picture of the brain and cognition as an open, living and dynamic system which does not easily render itself to complete description.

Cognition, as it emerges from various processes in the brain, is truly complex. However, if one were to stop at a mere description of cognition as a complex system, and not consider the processes by which such complex systems evolve, one would not know by which mechanisms cognitive change becomes possible. Gauvain (2001) insists that an understanding of the mechanisms of cognitive change is important, because

> Without an understanding of how change occurs, it is unclear what processes instigate and organize human intellectual development. It is evident from observations, across a wide range of contexts in which people develop and in the many domains of functioning in which the mind is capable of performing competently, that cognitive development proceeds in an organized fashion. This suggests that a set of common principles underlies much of what occurs over the course of intellectual growth (p. 22).

Various attempts have been made to explain the mechanisms by which cognitive development takes place. Candidates include Piaget's concepts of assimilation and accommodation, Vygotsky's Zone of Proximal Development (ZPD), the Behaviourist concept of reinforcement as a mechanism to strengthen stimulus-response bonds, and the information-processing concept of automatisation, to name a few. More recently, Gauvain (2001) has argued for social experience to be considered as the principle mechanism of cognitive change in informal contexts.

Although the mechanisms of cognitive change as proposed by various cognitive theorists do offer suggestions on how such cognitive changes can take place, they are by no means universal explanations for cognitive change on all levels of human experience. For example, Piaget was mostly concerned with changes in people's cognitive schemas, and less so with chemical or biological mechanisms of change. Vygotsky focused on the role of social interaction in conceptual change, but was less concerned with cognitive change on a physical level. Behaviourist theory altogether fails to account for the changes in complex systems such as cognition and language, whereas automatisation may describe skill acquisition adequately but fails to account for the complexities of emotional development. Even Gauvain’s (2001) proposal that social experience be viewed as the main mechanism of cognitive change does not make room for other contexts which are not necessarily social in nature, but in which learning also occurs.

Therefore, some of the questions that arise in terms of cognitive development, are whether such universal mechanisms of change exist, whether these mechanisms could be at the root of cognitive change, and whether they can shed light on the historical development of cognition as a complex system. In considering these questions, I believe it is important that universal mechanism(s) of change allow(s) psychologists to explain change at all levels of the complex system, irrespective of the context in which the change occurs. A universal mechanism of change will therefore have to be capable of coping with change on cellular, structural, psychological and social levels, and will therefore have to incorporate as a central feature, the notion of fractality, or self-similarity. Briggs and Peat (1999) describe fractality as follows:

> Nature’s patterns are the patterns of chaos. “Fractal” is the name given by scientists to the patterns of chaos that we see in the heavens, feel on earth, and find in the very veins and nerves of our bodies….fractals refer to the traces, tracks, marks, and forms made by the action of chaotic dynamical systems (p. 100).

Chaos and fractality would be central features of a universal mechanism of cognitive change. An important question is whether such a universal mechanism of change in complex systems can offer a sound basis for the development of a plausible framework, or a continuum of theory, as Goertzel (1993) has suggested[P1].

At present, it appears that the best candidate for such a comprehensive theoretical framework, may be chaos theory.

3.4 CHAOS THEORY

3.4.1 Origins of chaos theory

The question that meteorologist Edward Lorenz posed to his audience in 1972, namely “Does the flap of a butterfly’s wings in Brazil set off a tornado in Texas?” addressed a central feature of chaotic systems, namely sensitivity to initial conditions.

Lorenz was especially intrigued by tentative evidence that small perturbations could produce different weather systems that differed considerably in their nature and impact, suggesting that the global weather system was in fact unstable. Although Lorenz was unable to answer the question at the time, it stimulated the adoption of a whole new paradigm in the mathematical and physical sciences known as dynamical systems theory[19] (Lorenz, 1993).

In Section 3.4.2 I will discuss three key features of chaos theory, namely sensitive dependence, non-linearity and self-organisation. In each case I will point out the relevance of these features to the study of human cognition.

3.4.2 The core principles of chaos theory

3.4.2.1 Sensitive dependence

Lorenz (1993, p. 207) defines **chaos** as “the property that characterizes a dynamical system in which most orbits exhibit sensitive dependence; full chaos.” Chaotic systems show varying levels of chaos, and so the presence of chaos in a complex system does not refer to uniform state in the system. Rather, a chaotic system alternates between states of full chaos and states of organised chaos.

Masterpasqua and Perna (1997) describe chaos as

> The unpredictable and irregular evolution of the behaviour of many nonlinear dynamical systems. Because of their sensitive dependence on initial conditions, the error in predicting the future state of the system becomes essentially unknowable in a relatively brief period of time. Although *chaos* means unpredictability, it should not be understood to mean that the system was not or is not determined. After considerable debate, the Royal Society in London in 1986 defined *chaos* as “stochastic behaviour occurring in a deterministic system” (p. 304).

Sensitive dependence is also known as the *Butterfly effect*, and is defined by Lorenz (1993) as “the phenomenon that a small alteration in the state of a dynamical system will cause subsequent states to differ greatly from the states that would have followed without the alteration” (p. 206). Such alterations are known as bifurcations, defined as “an abrupt change in the long-term behaviour of a system, when the value of a constant is changed from below to above some critical value” (p. 206).

In essence, sensitive dependence refers to the fact that very small changes in the initial conditions of a chaotic system can change the trajectory of the system exponentially. As

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[19] The terms *dynamical systems theory* and *chaos theory* are often used synonymously.

Lorenz (1993) pointed out, ‘initial conditions’ need not refer to the conditions that were present at the time when the system was created, it may refer to any point in the evolution of the system which is chosen as the point from which the system will be observed and compared. It is from sensitive dependence that complex systems derive their non-linear character.

It can often be difficult to distinguish between chaos and complexity. To maintain a clear distinction between chaotic systems and complex systems, can be fairly difficult because many important features are shared between the two. For example, some of the characteristics which have been described as characteristics of complex systems will be revisited in the next section within the context of chaos. The most important distinction between chaotic systems and complex systems is that chaos is only one phase (albeit a very important one) in the emergence of a complex system.

It may help to bear in mind that all complex systems are chaotic, but chaotic systems are not necessarily complex. For example, Lorenz (1993) describes pendulums and pinball machines as simple systems which exhibit chaotic behaviour. On the other hand, complexity cannot emerge without chaos because chaos is necessary for self-organisation.

3.4.2.2 Non-linearity

(1) Definition

A **non-linear system** is defined as “a system in which alterations in an initial state need not produce proportional alterations in subsequent states” (Lorenz, 1993, p. 210) and by Masterpasqua and Perna (1997, p. 306) as “the concept that qualitative, not quantitative, change describes the dynamic course of a system across time or that small changes early on can result in unpredictable changes late in development.”

The concept of non-linearity was already introduced in the context of complex systems in section 3.3.3.7 by considering how non-linearity is expressed on a physiological level in the brain. In this section I will address non-linearity within the sociocultural context and attempt to highlight the usefulness of the concept in the study of cognition.

(2) Non-linearity and Vygotsky’s psychology

The non-linearity of human development was described earlier by Vygotsky (1935/1978) when he remarked that

> Child development is a complex dialectical process characterized by periodicity, unevenness in the development of different functions, metamorphosis or qualitative transformation of one form into another, intertwining of external and internal factors, and adaptive processes which overcome impediments that the child encounters. Steeped in the notion of evolutionary change, most workers in child psychology ignore those turning points, those spasmodic and revolutionary changes that are so frequent in the history of child development….Where upheavals occur, where the historical fabric is ruptured, the naïve mind sees only catastrophe, gaps, and discontinuity (p. 73).

Within the context of chaos theory, *catastrophe* and *discontinuity* are no longer seen as “upheavals” , but are recognised as creative moments that allow complex systems to evolve to a higher order through a process of self-organisation. Vygotsky (1935/1978) rejected the traditional view of cognitive development as the result of the gradual accumulation of separate changes. According to Wertsch (1985), it was the revolutionary shifts in the development of thinking that interested Vygotsky. As a result, Vygotsky (1935/1978) was adamant that experimental methods should encourage moments of catastrophe and discontinuity if one were to discover how children organise their behaviour.

Vygotsky (1935/1978) reiterated that

> What is crucial is that in all these cases we must adhere to one principle. We study *not only the final effect of the operation, but its specific psychological structure.* In all these cases, the psychological structure of the development appears with much greater richness and variety than in the classic method of stimulus-response experiment. Although stimulus-response methodology makes it extremely easy to ascertain subjects’ responses, it proves useless when our objective is to discover the means and methods that subjects use to organize their own behavior (p. 74, author’s emphasis).

The Behaviourist stimulus-response mechanism of cognitive change used to be very influential in the development of school curricula, where it led to instructional approaches that were teacher- and curriculum-centered, with an emphasis on the mastery of content (Lerner, 2000). Since behaviourist approaches to learning tend to focus on reducing the complexity of learning content, rote learning, and stepwise mastery of discrete skills, ambiguity in the presentation or solution of problems is rarely tolerated or encouraged. By contrast, Vygotsky (1935/1978) believed that a disruption of automatised processes caused by presenting children with unfamiliar or advanced problems, disrupted children’s cognitions and thus allowed him to observe the psychological process by which children attempt to organise their learning experiences.

(3) Non-linearity and Vygotsky's zone of proximal development (ZPD)

Even though the birth of chaos theory and complexity theory would take place many years after Vygotsky's death in 1934, I suggest that it was essentially Vygotsky's tacit acknowledgement of the chaotic and complex nature of cognition that led him to introduce the concept of the zone of proximal development (ZPD).

The ZPD is defined as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers." (Vygotsky, 1935/1978, p. 86). The ZPD therefore defines functions that are in the process of maturation, in an embryonic state as it were (Vygotsky, 1935/1978). Wertsch (1985) describes the ZPD as "a dynamic region of sensitivity" (p. 67) where the transition from social speech to inner speech is made. Vygotsky's psychology is, as is chaos theory, essentially concerned with the study of change and more specifically, the nature and the mechanisms of change.

Vygotsky (1935/1978) further said of the ZPD that it provides psychologists with a tool through which to understand the internal course of development because it permits one to discover the child's immediate future and his "dynamic developmental state, allowing not only for what already has been achieved developmentally but also for what is in the course of maturing" (p. 87). In essence, the ZPD is therefore a tool that allows the study of non-linear change in a complex system.

Vygotsky's formulation of the ZPD and the conceptual foundation on which it rests have two major implications for cognitive education. The first implication is that chaos and ambiguity are necessary (although not sufficient) features of cognition. The further implication is that approaches to cognitive intervention could perhaps consider introducing ambiguity and complexity purposefully in problem solving in an attempt to encourage chaos since chaos appears to be a necessary precondition for self-organisation.

Both of the aforementioned implications can be linked to Vygotsky's (1935/1978) conceptualisation of the relation between learning and development in children. Vygotsky (1935/1978) proposed that learning (and by implication, teaching) should not be oriented towards developmental levels that have already been reached, but should be pitched at a level higher than current development. It means he viewed learning and teaching as processes that can stimulate cognitive change by periodically introducing chaos, from which higher levels of cognitive organisation become possible. Referring to the relation between learning and development, Vygotsky (1935/1978) remarked that

> Although learning is directly related to the course of child development, the two are never accomplished in equal measure or in parallel. Development in children never follows school learning the way that a shadow follows the object that casts it. In actuality, there are highly complex dynamic relations between developmental and learning processes that cannot be encompassed by an unchanging hypothetical formulation (p.91).

The ‘complex dynamic relations’ that Vygotsky speaks of is relevant to another central feature of chaotic systems, namely their ability to use chaos as a means of evolving to higher levels of self-organisation. A system is in a state of chaos when it exercises its maximum degrees of freedom. It is believed that these states of chaos can be described as a state of maximum readiness for order to emerge (Masterpasqua & Perna, 1997). Using the brain as an example of a chaotic system, Masterpasqua and Perna (1997) cite a number of studies that seem to indicate that the chaotic activity of brain waves seems to increase the greater the mental challenge or novelty of a task, suggesting that self-organisation from chaos may be a fundamental aspect of cognitive problem solving. Further, a body of evidence appears to be accumulating which suggests that the central nervous system is a complex dynamical system, and that a number of disease states, such as epilepsy, manifest themselves through a loss of complexity in brain functioning (Masterpasqua & Perna, 1997).

However, it is important to note that complex systems are not chaotic all the time, they merely possess the capability to alternate between chaotic and stable phases. Secondly, chaotic phases are viewed as an essential quality of complex systems, because it is from chaos that higher order is thought to emerge (Masterpasqua & Perna, 1997). The emergence of order from chaos is often referred to as the system’s potential for self-organisation and it is believed that systems in chaos are those most capable of reorganisation (Masterpasqua & Perna, 1997).

3.4.2.3 Self-organisation

(1) Descriptions of self-organisation

Masterpasqua and Perna (1997) describe self-organisation as “order for free” (p. 307). Mahoney and Moes (1997) describe self-organisation as the “ongoing and spontaneous emergence of self-order” (p. 183).

Cilliers (1998) asserts that self-organisation is a general property of a complex system because self-organisation is what gives a complex system its plasticity, i.e. it allows the system to develop and change its internal structure spontaneously and adaptively in order to cope with unpredictable changes in the environment.

Self-organisation may be observed at various levels within the same system. In terms of the brain, self-organisation is evident on a cellular level as neuronal cells organise themselves to perform a particular function, and it is also evident on a molecular level as atoms organise themselves into chemical structures that facilitate brain functioning in various ways. The integrated and self-organised functioning of the brain may be what allows the mind to emerge and may also give rise to the brain’s most unique, but poorly understood property: consciousness.

Cilliers (1998) elaborates on a number of general attributes of self-organising systems.

(2) Non-determinism

The structure of a self-organising system is not considered to be the result of an *a priori* design, but of complex interactions between the system and the environment. At any point in a child’s lifetime it means that the environment exerts a powerful influence on the brain being what it is, and becoming “what it not yet is” (Vygotsky, 1935/1978).

The most compelling evidence of the brain’s non-deterministic nature comes from research that points to the critical importance of the environment in brain development. For example, Richek, Caldwell, Jennings & Lerner (2002) report on research that shows that brain development before age one is more rapid and extensive than previously realised, that brain development is much more vulnerable to environmental influences than suspected, and that the environment affects the number of brain cells, connections among them, and the way connections are wired.

Richek *et al.* (2002) further estimate that one third of the American nation’s children are at risk for school failure before they enter *kindergarten* because they have been subjected to environmental stresses such as malnutrition and smoking during the mother’s pregnancy, child abuse and lack of early cognitive and language development. In South Africa, a large part of the population experience extreme poverty which is known to be related to low achievement in school (Richek *et al.,* 2002).

(3) Dynamic adaptation

Because the environment with which a complex system interacts is unpredictable, the internal dynamics of the complex system must be able to handle such unpredictabilities through dynamic adaptation. It is impossible to say exactly which situations any person will face in her life time, and so it is important that the brain has the resources to deal with most eventualities.

As children grow up, they are subjected to a variety of influences in social, emotional and cultural contexts in the home and school environment. Children learn to negotiate unpredictable events in their environment through dynamic adaptation. Sometimes children adapt successfully, but when they don't, they may experience emotional difficulties such as anxiety, low self-esteem, depression, learned helplessness and hostile-aggressive behaviours which are associated with low achievement in school (Richek *et al.,* 2002).

Dynamic adaptation essentially refers to the self-organising system's capacity to be flexible in its repertoire of responses. Flexibility in response can be observed at all levels of a complex system. In the case of the brain, flexibility may refer to *physiological flexibility* (higher activation of appropriate brain regions in response to particular tasks), *emotional flexibility* (adaptive and appropriate emotional responses to various situations), and *cognitive flexibility* (interpreting the demands of a situation, generating suitable alternatives and orchestrating an appropriate verbal, emotional and behavioural response).

At times, constraints within the system such as visual impairment, hearing impairment and neurological factors may restrict the system's capacity for flexible response. For example, with reference to neurological factors, Richek *et al.,* (2002) report that fMRI has shown patterns of underactivation of the large posterior regions of the brain, and overactivation in the anterior brain regions in dyslexic subjects. Richek *et al.,* (2002) also cite research that appears to confirm the fact that dyslexia may be caused by an abnormality in brain structure, difference in brain function, and genetic factors. In addition, Pennington (1999) suggests that dyslexia may be due to a genetic susceptibility locus that may cause variations in reading skill or make a child vulnerable to the development of dyslexia. Because a genetic susceptibility locus is neither necessary nor sufficient for the development of dyslexia, Pennington (1999) argues that the development would necessarily have to include other factors related to brain structure and cognition.

The factors that could potentially influence the development of dyslexia can be viewed from a neurodevelopmental perspective (Pennington, 1999) as well as a deficit perspective (Rapp, 2001). It would appear as if a neurodevelopmental perspective emphasises the emerging, self-organising (plastic) capacity of the brain more than does a deficit perspective that appears to emphasise a structural non-variance in cognitive architecture (Pennington, 1999). Nevertheless, both perspectives acknowledge that reading is a complex skill that requires a flexible and integrated response in terms of activation of brain structures and also in terms of cognitive processes (lexical and sublexical) involved, and that genetic and structural deficits, as well as variations in brain functioning, can inhibit or impair the individual's ability to generate a flexible and integrated response to a complex task.

Loss of flexibility, and by implication impaired ability to adapt dynamically to the environment, is almost always associated with a lack of complexity and an increase in rigidity, at least in chaos theory. For example, Briggs and Peat (1999) suggest that mental illness, which appears to be chaotic (Tschacher & Scheier, 1997), can actually be viewed as the reverse of chaos, because "mental illness occurs when images of the self become rigid and closed, restricting an open creative response to the world" (Briggs & Peat, 1999, p. 29). As a result, the system experiences a reduction in its degrees of freedom and may organise itself around a limited and restrictive pattern of behaviours, also known as a periodic attractor[20].

The point is that adaptation to the environment requires a complex system to achieve a dynamic balance between chaos and order. Whenever a complex system fails to use chaos or disequilibrium to self-organise, the system becomes closed off to the environment. When a complex system finds itself organised exclusively around chaos and disequilibrium, it is also rigid in its development because it fails to reach higher levels of integration. The presence of chaos in itself is not necessarily good or bad, it is the response of the system to such perturbations that determine whether it is adapting or not. Similarly, the presence of learning opportunities (as potential perturbations) in the lives of children are not by and of themselves good or bad, it is how the child respond to such learning experiences that determine whether the child will reach higher levels of development or not.

Since a child's behavioural response represents the outcome of an integrated process which involves genetic, structural, and cognitive factors, it follows that a deficit in terms of any of these processes has the potential to limit the quality and flexibility of the total response on a behavioural level. It is also important to note that chaos deals with the basic mechanisms by

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[20] Masterpasqua and Perna (1997) define a periodic attractor as a pattern of behaviour in phase space which shows never-ending repetitions of the same behaviour.

which complex systems are thought be become capable of changing *i.e.* self-organising. Chaos theory does not explain the very specific cognitive processes by which disorders such as dyslexia develop, but it does provide a plausible explanation of the underlying mechanisms of change that enable the development of such disorders.

(4) Dynamic non-linear relationships

Self-organisation is not the result of a linear process of feedback. Cilliers (1998) mentions, for example, that a thermostat that responds to its environment by switching itself on and off, is dependent on a linear set of information, and this precludes it from being called a self-organising system. Reflecting on the evolution of the brain, Cairns-Smith (2000) suggests that, contrary to popular depictions of the brain as a kind of computer, primitive brains were more like thermostats than computers.

Modern technologies that incorporate fuzzy logic, such as washing machines and microwave ovens, though they are more responsive than ordinary appliances, are not yet self-organising. Although these systems are more capable of responding to information in the environment, they have to be designed with such capability in hand. Moreover, self-organising systems preclude the necessity of an external designer because they create their own internal structure through their interaction with their environment. Cairns-Smith (2000) refers to self-organisation as self-assembly and offers the following amusing example:

> A dew drop, a soap bubble, or a sugar crystal are familiar examples of self-assembled objects: they are higher-order structures whose molecules have come together (in a more or less organised way) and hold together (more or less firmly) under the combined influence of kinetic motion and secondary forces. This is not like the construction procedures of human engineering; at least I have not heard of machines being put together just by shaking up pre-made components….Self-assembly is the "hands off" part of the construction system of cells. The secondary-tertiary folding of a protein chain is an excellent example of it: this folding occurs more or less spontaneously without detailed external control (p. 78).

The "hands-off" aspect of self-assembly that Cairns-Smith (2000) mentions is indicative of the main characteristic of a self-organised system: the absence of an external designer because self-organisation (or self-assembly on a molecular level) can only occur if the relationships (feedback loops as they were discussed in section 3.3.3.9) among the components of the system allow for spontaneity, i.e. non-linearity.

(5) Emergent property

This feature refers to the relationship between the elements of the system and the system as a whole. The elements of the system are ignorant of the behaviour of the entire system, and so the complexity in self-organising systems is considered to be an emergent property of the system.

For example, it has been suggested that the mind is an emergent property of the brain (Groves & Rebec, 1992), and so it is not possible to reveal the complexity of the mind by focusing on discrete elements in the brain only. Cilliers (1998) further points out that the various levels of the complex system cannot be given independent descriptions because they are intertwined with the behaviour of the system as a whole, although they do not "know" the large-scale effects they can produce on the total behaviour of the system.

(6) Increasing complexity

Self-organising systems are not stable. They increase in complexity because they have the ability to learn from experience.

Cilliers (1998) suggests that it is the system's increasing complexity that may explain why self-organising systems age, because complex systems are bound by the constraints of a physical world and will inevitably become saturated at a certain point. However, I believe that such a view may be somewhat simplistic. Saturation in terms of complexity does not explain why, for example, the synaptic density in the visual cortex of humans reaches a peak in childhood (approximately 9 – 11 years) and then declines markedly throughout the further lifespan (Groves & Rebec, 1992). Secondly, a saturation model of aging would fail to address the aging process at all levels of the human body (a complex system in its own right). For example, certain chemical reactions at a molecular level (e.g. the formation of free radicals in response to high frequency ultraviolet radiation) that are known to damage cells and accelerate aging, cannot be explained adequately in terms of increasing complexity alone.

Moreover, Groves and Rebec (1992) report that aging is associated with the loss of large numbers of neurons and glial cells since the size and weight of the human brain begin to decrease when individuals reach approximately fifty years of age. However, physical exercise has been shown to reverse the effects of aging on some functions of the central nervous system such as reaction time and brain signals associated with decision making (Groves & Rebec, 1992).

I would therefore propose that a linear association between self-organisation and saturation directly contrasts with the notion of non-linearity in complex systems. All living systems operate within certain genetic constraints, genetic information being one of the variables present in the initial conditions of a system. Knowing that complex systems are sensitive to initial conditions, it may help to explain why there is such variability in the aging process among individuals, and also why certain environmental influences can accelerate or slow down the aging process.

(7) The necessity of memory

Of course, learning from experience involves some form of memory, which Cairns-Smith (2000) argues is not only situated in the structures of the limbic system, but also on a microscopic level in and among cells and their molecules. Here, Cairns-Smith (2000) refers to the phenomenon of "long-term potentiation" in which signals become easier to pass between neurons and which is thought to provide a basis for associative learning.

The memory of a complex system is tied to its history. In this regard, Cilliers (1998) suggests that the history of a complex system should form an important facet of its study, since the system's history reflects the conditions from which it emerged. The assumption that a system's history is important to its understanding was also central to Vygotsky's scientific method. Vygotsky (1930/1978) formulated two principles that formed the basis of his approach to the study of cognitive development: process *versus* object, and explanation *versus* description.

(a) Process versus objects

It was important to Vygotsky to distinguish between psychological analysis that treated psychological processes as fixed, stable objects and psychological analysis that emphasised their historical origin (Vygotsky, 1930/1978).

Emphasising the history of psychological processes by focusing on their developmental and dynamic nature prompted Vygotsky to develop, what he termed, an "experimental-developmental" method of investigation which artificially provokes or creates a process of psychological development (p. 61). As stated in paragraph 3.4.2.2.2, provoking development in his view had much to do with instigating chaos and disrupting automatised patterns of thought in order to discover how thought develops.

(b) Explanation versus description

To comprehend how the history of a complex system can inform our understanding of it, Vygotsky (1930/1978) thought it important to distinguish between phenotypic and genotypic analysis. Whereas phenotypic analysis focuses on the description of externally observable features, genotypic analysis aims to explain a system on the basis of its origin (Vygotsky, 1930/1978). By studying a system developmentally, Vygotsky wanted to understand its causal dynamic basis, its genesis. Vygotsky (1930/1978) acknowledged that, although some systems may appear to be similar in terms of their external manifestation, they may differ profoundly in terms of their origin and nature, and "in such cases special means of scientific analysis are necessary in order to lay bare the internal differences that are hidden by external similarities" (p. 63).

(8) Functional description

Cilliers (1998) asserts that it is often difficult to talk about the function of a complex system because doing so often introduces an external reason for the structure of the system.

The function of a system can often be described only in terms of a specific context (Cilliers, 1998). For example, while it is quite plausible to talk about the function of the frontal lobes, visual cortex, or some other part of the brain in cognition, it is much more difficult to talk about the function of the mind, or consciousness for that matter. Doing so, would immediately invoke an external designer who, by implication, constructed the system for a particular purpose. Self-organisation cannot be driven by the attempt to perform a particular function (Cilliers, 1998).

Self-organising systems emerge toward greater complexity as a result of interactions with their environments. The presence of non-linearity within these systems as a function of their sensitivity to initial conditions, makes it difficult to determine or predict exactly the precise developmental trajectory of the system. Yet, certain characteristics of a complex system are determined to some extent by their initial conditions, such as genetic make-up. It is such determinism that makes it possible for humans to develop along roughly the same lines.

For example, Groves and Rebec (1992) report that, as the nervous system matures, neuronal cells "know" they must migrate to specific areas in the cortex before they specialise to fulfill their function in the brain. Such evidence perhaps describes what is meant by deterministic chaos, i.e. a complex system may appear to be random, but is not. In fact, periods of chaos are only transient states which enable the system to self-organise.

3.4.3 The relevance of chaos theory to the study of cognition

3.4.3.1 Chaos at all levels of the central nervous system

In the preceding sections numerous examples were provided of evidence that appears to support a chaotic view of cognition on various levels. On a physical level, cognition manifests itself through structural change, as well as complex electrical and chemical processes in the central nervous system. The structural changes and processes in the brain show some of the hallmarks of chaos because they are sensitive to initial conditions, are characterised by non-linear interactions, and show a remarkable capacity for self-organisation.

The brain's capacity for self-organisation is partly what makes the emergence of the mind possible. The mind is a psychological construct rather than a physical one and is thought to refer broadly to conscious and unconscious processes (Cairns-Smith, 2000). By contrast, cognition can refer to a *physical* construct (when we describe metabolic activity in the brain during a problem solving task), a *psychological* construct (when we describe cognitive skills and strategies such as categorisation and problem solving), a *social* construct (when we emphasise joint problem-solving and collaborative learning) or a *cultural* construct (when we view cognition as the internalisation of cultural patterns of social interaction).

Irrespective of which aspect of cognition we address, the fact remains that cognition arises from the brain. Since the brain is a complex and chaotic system, it is logical to expect that which emerges from it (cognition) to show the same properties. One would not expect complex and chaotic behaviour to evolve from a simple, linear system (such as a computer, for example) any less than one would expect simple and linear behaviours to emerge from a complex, non-linear system. Whether we are engaged in studying the physical aspects of the brain, or developing a psychological theory of cognition in the brain, or whether we are interested in describing the social and cultural dimensions of cognition, we have to ensure that our theory can form a continuum between two extreme points. On the one extreme are those phenomena which are closely related to our observations of the physical world, namely the brain. The other extreme represents a psychological universe, one which is removed from direct experimental reality, which contains the social and cultural nature of cognition.

Goertzel (1993) has already pointed out that complex systems science (incorporating complexity and chaos) may be the key to a common psychological theory, and I agree. One of the distinguishing characteristics of chaotic systems is a measure of self-similarity (fractality) which arises from deterministic chaos. Self-similarity refers to the repetition of certain patterns on different levels of magnification. A tree is a good example of a natural fractal form. The tree's basic pattern remains the same, whether one is observing the entire tree, a branch or even a twig. A mountain range is another example. The same degree of roughness is evident on different levels of magnification, so that the mountain range mirrors itself on an increasingly minute level. Natural fractal forms (ferns, butterflies) have also been created with mathematical equations that behave chaotically, providing further evidence that the universal mechanisms which underpin the evolution of all natural phenomena are chaotic by nature. It is perhaps not surprising that our models of our universe on a macro-level and our models of atoms (on a micro-level) show the same type of fractality: a nucleus (the sun) with revolving electrons (planets). Exhibit A shows some examples of fractal forms.

The human body also shows self-similarity in the sense that chaotic behaviour and self-organisation are evident on different levels of magnification. Whether we are considering synaptogenesis, metabolic activity, specialisation and localisation in the brain, cognition, emotion and behaviour, all are governed by chaotic processes that, combined, make possible the emergence of the mind. The principles of chaos theory can explain the emergence of cognition on a physical, psychological, social and cultural continuum more effectively than any other theory of cognition because it is not bound by the constraints of a particular context. Chaos theory decribes universal patterns of evolution in nature and helps to focus our attention on the fundamental mechanisms of change in complex living systems. In respect of the present study, the principles of chaos theory are understood to form the universal mechanisms of cognitive change and development. We turn our attention now to some practical and applied aspects of chaos theory, namely its implications for the development of cognitive theory and the practice of cognitive intervention.

3.4.3.2 Implications for research : cognitive theory

Cairns-Smith (2000) warns that

> "we may set up our chess board with a restricted number of pieces operating under a restricted set of rules. And we may have fun for a time and gain new insights; but sooner or later, if history is anything to go by, we will lose touch with the game that Nature is playing" (p. 49).

The game that Nature is playing requires a “playful approach” (Cilliers, 2000), one that recognises its complexity (Goertzel, 1993) and addresses its chaotic qualities (Lorenz, 1993).

Cairns-Smith (2000) made the above statement in the context of a discussion about scientific models and warned that although one can learn much from constructing models (analogies) of reality, it would be wise not to view scientific models as reality. I believe that this is what is happening in cognitive psychology, where psychologists’ model of the brain as a computer has become so pervasive that the brain is actually viewed as a computer. Scientific model and reality have become one and the same thing. For this reason, cognitive psychology has lost touch with the “game that Nature is playing” although new insights have been gained.

To apply the metaphor of Cairns-Smith (2000), cognitive psychology has set up a chess board (cognition) with a limited number of pieces (cognitive components) operating under a restricted set of rules (information processing). From previous sections we have seen that the brain may appear to be deceptively linear, but that the linear processes are governed by associative and quantum processes that behave chaotically. There are more fundamental rules (universal mechanisms of change) that form part of Nature’s game. Eliminating them also eliminates any chance of discovering the true complexity of cognition.

If psychologists who study cognition wish to avoid losing touch with Nature’s game, they have to become more receptive to the complexities of cognition by not restricting the playing field unneccessarily through controlled experiments and rigidly defined variables. Instead of manipulating cognition, psychologists have to allow it to emerge naturally.

3.4.3.3 Implications for practice : cognitive intervention

Cognitive theory is about the nature of cognition and cognitive change and development. It is inevitable (and desirable) that cognitive theory will inform the praxis of cognitive intervention in research and applied contexts.

There is no doubt that the relationship between theory and application is a linear one because simplistic theories lead to simplistic applications of those theories. For example, the behaviourist theory that views cognition as the formation of S-R bonds will in its application (and depending on its goal) look for ways to strengthen or extinguish S-R bonds. Information-processing approaches to the study of cognition which deal with the study of cognitive components and processes such as attention and memory, likewise will emphasise the importance of attention and memory in learning.

The theoretical framework presented in this study emphasises the complexity of children's thinking. Since the theoretical framework will necessarily influence the application of theory in research and applied contexts, it is to be expected that, in terms of the research in the present study, the research method will in all likelihood study cognition as a complex phenomenon by not restricting the investigation to include only variables that can be controlled. In fact, we may assume that the whole notion of experimental control over variables might have to fall away, leaving the researcher and her subjects to deal with ambiguity and uncertainty. Thus the accommodation of chaos and complexity in the research method will have far-reaching implications for the choice of research instruments, data collection and data analysis.

Cognition will have to emerge naturally within an unrestricted context. Consider the following statement by Schostak (2002):

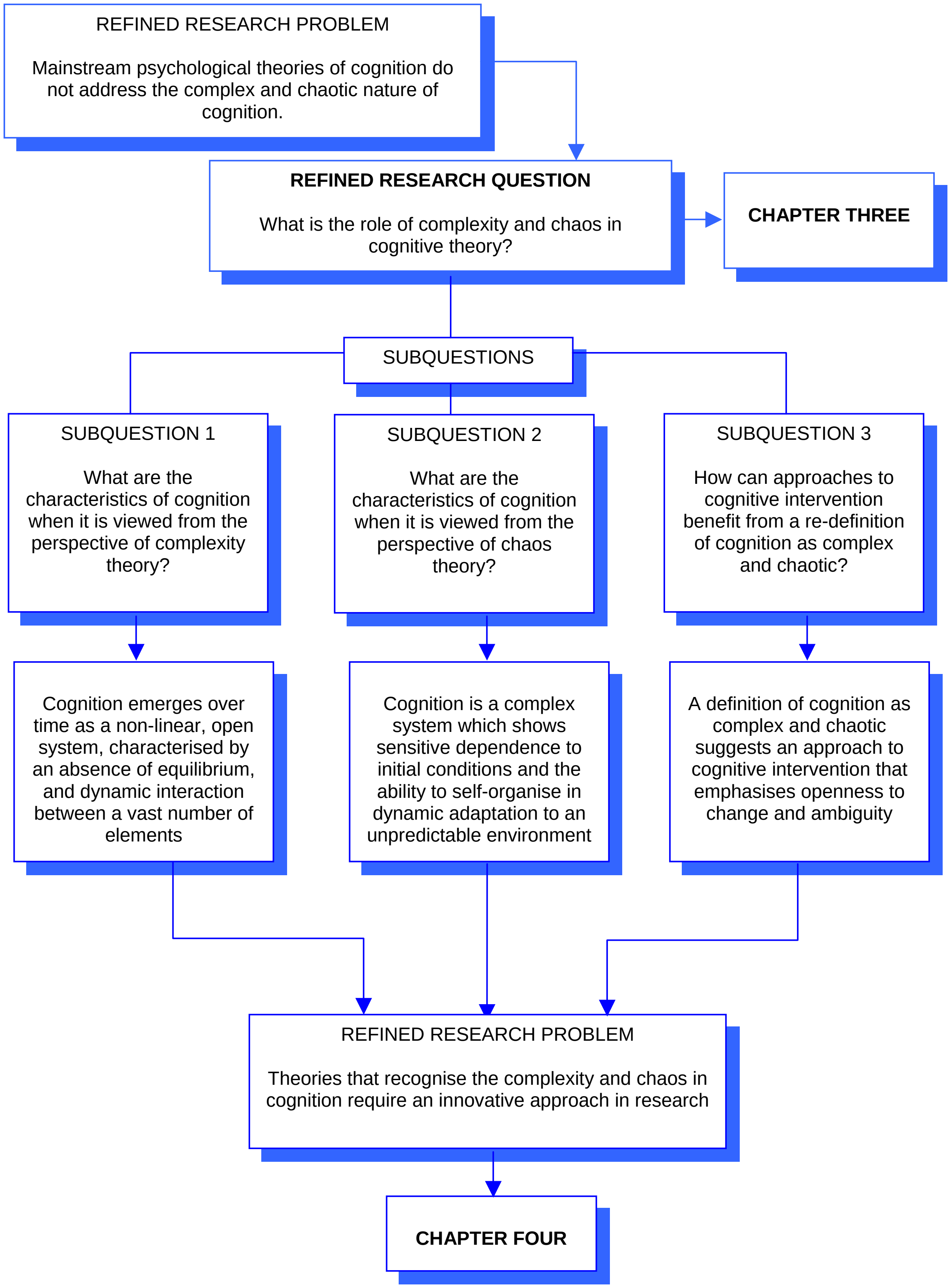
> How then does one handle this incredible complexity and uncertainty that seems inextricably melded with the nature of being an individual within the multiple possible and actual 'worlds' of everyday life? One solution has been to ignore it. The principal rule adopted by many is to simplify in order to control. Thus, for example, by concentrating only on what can be seen and measured all the messy feelings, emotions and 'insideness' of human life can be eliminated from the equations, the models, the procedures by which to explain and control individual and social life (p. 93).

Instead of trying to control complexity and uncertainty in research, one should embrace it because "complexity and uncertainty is not to be feared and shunned but is the lure, the field of research that never ceases to amaze" (Schostak, 2002, p. 94). Likewise, in an applied context where cognitive intervention takes place, complexity and chaos require embracing a view of learning as a process of self-organisation where order evolves from chaos. Self-organisation reflects a process during which children are confronted with uncertainties and ambiguities and learn how to make sense of them, all the while learning to integrate experiences into a meaningful whole. When children begin to learn how to manage the process of making sense of ambiguity and uncertainty on a metacognitive level, they are also beginning to learn how to self-regulate their own learning behaviour. One may perhaps even say that self-organisation essentially refers to a cognitive process, whereas self-regulated learning reflects an executive process that adds a metacognitive component to learning.

One can then expect that the learning situation should not be controlled, but as Vygotsky (1935/1978) suggested, should employ ambiguity in such a way as to disrupt learners' normal thinking processes in order to make self-organisation and therefore also the emergence of self-regulated learning, possible.

In Chapter Four I will address in greater detail the principles of complexity and chaos in an applied context. Research conducted with children in the first three school years (Foundation Phase) at an inner-city school will provide the context for the discussion.

META-NARRATIVE 3.3



REFINED RESEARCH PROBLEM

Mainstream psychological theories of cognition do not address the complex and chaotic nature of cognition.

REFINED RESEARCH QUESTION

What is the role of complexity and chaos in cognitive theory?

CHAPTER THREE

SUBQUESTIONS

SUBQUESTION 1

What are the characteristics of cognition when it is viewed from the perspective of complexity theory?

SUBQUESTION 2

What are the characteristics of cognition when it is viewed from the perspective of chaos theory?

SUBQUESTION 3

How can approaches to cognitive intervention benefit from a re-definition of cognition as complex and chaotic?

Cognition emerges over time as a non-linear, open system, characterised by an absence of equilibrium, and dynamic interaction between a vast number of elements

Cognition is a complex system which shows sensitive dependence to initial conditions and the ability to self-organise in dynamic adaptation to an unpredictable environment

A definition of cognition as complex and chaotic suggests an approach to cognitive intervention that emphasises openness to change and ambiguity

REFINED RESEARCH PROBLEM

Theories that recognise the complexity and chaos in cognition require an innovative approach in research

CHAPTER FOUR