Complexity and Classroom Learning

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Abstract

This thesis provides a theoretical basis for applying complexity theory to classroom learning.

Existing accounts of complexity in social systems fail to adequately situate human understanding within those systems. Human understanding and action is embedded within the complex systems that we inhabit. As such, we cannot achieve a full and accurate representation of those systems. This challenges epistemological positions which characterise learning as a simple mechanistic process, those which see it as approaching a view of the world 'as it is' and also positions which see learning as a purely social activity.

This thesis develops a materialist position which characterises understandings as emergent from, but not reducible to, the material world. The roles of embodied neural networks as well as our linguistic and symbolic systems are considered in order to develop this materialist position. Context and history are shown to be important within complex systems and allow novel understandings to emerge. Furthermore, shared understandings are seen as emergent from processes of response, replication and manipulation of patterns of behaviour and patterns of association. Thus the complexity of learning is accounted for within a coherent ontological and epistemological framework.

The implications of this materialist position for considering classroom learning are expounded. Firstly, our models and descriptions of classrooms are reconciled with the view of our understandings as sophisticated yet incomplete models within complex social systems. Models are characterised as themselves material entities which emerge within social systems and may go on to influence behaviour. Secondly, contemporary accounts of learning as the conceptual representation of the world are challenged.

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1 Introduction

1.1 The Contribution of this Thesis

This thesis seeks to:

1. Establish an ontological and epistemological basis for the application of complexity theory to classroom learning.

2. Evaluate the implications of this theoretical position in understanding classroom learning.

Describing classroom learning as complex is compelling because it speaks of the unpredictability of classrooms and the rich nuances of how individuals learn. However the application of complexity theory within education remains marginal. We will see that complexity theory is an umbrella term for a broad range of approaches, understandings and models which originated within the natural sciences but which is increasingly associated with social systems. There are considerable sites of conflict and contradiction in the ontological and epistemological claims made by complexity theorists and this is a barrier to its application to classrooms.

As well as a lack of a coherent theoretical basis in itself, complexity theory in the social sciences has yet to resolve specific issues associated with human understanding[1]. Firstly, we cannot dismiss or reduce the importance of understandings in relation to human action. In applying approaches from the natural sciences many researchers reduce learning to a mechanistic process, or omit human understandings from their models altogether. This will not suffice in relation to classrooms, where human understanding is the primary concern. Conversely, we cannot assume that our understandings are accurate and complete representations of the broader world. In a complex system the smallest detail may determine how the system develops, so our understandings can never be complete. The consequence of this is that we must redefine the relationship between our understandings and the world, which is no small task. A further issue stems from recognition that human understandings are not purely individual, but that as a species we have the capacity to learn from each other and to use symbolic and linguistic systems to understand the world. In Chapter 2 we shall expand upon and explore these issues as they occur within existing literature. Here we are able to say that learning is about developing understandings of the world but complexity presents

[1] We will develop our usage of the term 'understanding' in Chapter 2; see Glossary of Key Terms at the end of this thesis.

significant challenges in situating these understandings. The original contribution of this thesis lies in firstly expounding these challenges and secondly providing a solution to them.

It should be noted from the outset however, that this thesis contains no primary evidence in relation to classrooms, nor does it engage in empirical enquiry. The focus upon classrooms is intended to provide a conceptual frame in which to consider learning at the level of individuals and small groups of pupils, as well as teachers. This frame allows the thesis to focus upon such learning without considering the interactions of large populations of people, or the broader 'learning' of educational institutions and systems. Whilst many of the arguments within the thesis might be applied to learning beyond the classroom, focusing upon the classroom as a specific system allows a more detailed description of the theoretical issues which face the application of complexity theory to learning. In the concluding chapter we will lay out how engagement with real classrooms might further this thesis (see 8.3.2). However, there are considerable theoretical issues to be addressed first.

This introductory chapter is therefore concerned with elucidating the theoretical problems of applying complexity to classroom learning, as well as signposting the way that this thesis will approach the solution. In Section 1.2 we will define complexity theory and in doing so highlight both the difficulties and appeal of bringing it to bear on classrooms. Section 1.3 will consider further the issues in relating complexity theory to social systems, in which human understandings play a role. Thus, by the time we get to Section 1.4 we will be ready to begin considering the solution and how we will approach it.

1.2 What is Complexity Theory?

1.2.1 Deterministic Chaos

Having outlined the focus of this thesis, the rest of this introductory chapter will establish the problem at hand. We shall begin by developing a working definition of complexity through contrasting it to its historic precursor: deterministic chaos. Exploring the subtle differences between chaos and complexity will allow us to expound the difficulties of defining complexity in a general way, which has bearing on how it may be applied to classrooms.

Poincare is generally credited with first identifying deterministic chaos in the 1880s, through his work on the trajectories of three or more celestial bodies interacting through gravitational attraction. He noted that the orbits can vary (be non-periodic) without a discernible pattern, despite being clearly defined by equations of motion. Work at a similar time by Lyapunov investigated 'stability' in such systems and later mathematicians such as Birkhoff, Levinson and Smale built on these descriptions of dynamic systems (Gleik, 1987, p. 182). However it was not until the advent of sufficiently advanced computers that the behaviour of such systems over time could be modelled. Lorenz, working on a computer simulation of the weather in 1961 rounded-off the values he entered into his computer to three decimal places instead of six, and found that the model quickly diverged to give a considerably different forecast of weather. This was followed by the work of Feigenbaum in describing mathematically the sudden divergence (*bifurcation*) of systems under certain conditions, providing a broad description of systems which tend towards what is now known as chaos.

Lorenz defines "a chaotic system as one that is sensitively dependent on *interior* changes in initial conditions" (Lorenz, 1993, p. 24) [original italics]. A system may be sensitive to the exterior environment, but this does not necessarily mean it is chaotic. A chaotic system will evolve in a way that is sensitive to the variables *interior* to that system. This evolution is the product of the interactions of variables in a *nonlinear* way. In physics, linear dynamics refers to situations in which the variables only interact through addition and subtraction. So if input A will produce output B, and input C will produce output D, then inputting A + C will produce B + D. The addition of the inputs simply leads to the addition of the outputs; the fact that both are occurring at the same time does not affect the output overall. These systems can be described by linear mathematical equations. An example of a linear system is a chord played on a piano. Each note is not influenced by the others, the sound waves simply add together and our ear hears them all at once. Nonlinear dynamics deals with situations in which this is not the case. There are interactions between variables such that the output is influenced by the product of the inputs in some way. These are described mathematically by nonlinear equations (e.g. containing terms A^n or AB) which mean that the output is not simply proportional to the input. As Lorenz discovered in his weather models, a slight difference in inputs could lead to significantly different outputs. As such the trajectory of a chaotic system quickly escapes our ability to discern a pattern and the system appears to be behaving in a random way.

Despite appearances, a chaotic system is not random at all: it is *determinate*. A chaotic system is mathematically determined by a set of nonlinear equations and as such, if we had sufficient computing power, we could predict the future of the system. A *phase diagram* is often used to visualise the trajectory of a system, which plots different variables as different axes of a graph[2]. Chaotic models that show no discernible pattern in these plots over the short term, may nevertheless display recognisable patterns in their trajectories over longer periods of time. An a*ttractor state* is a state that a system tends towards over time such as an equilibrium position. For example, a pendulum under the action of gravity and friction alone will always come to a standstill at its lowest point (known as a singularity). A system may instead tend to an attractor that is a cycle of different states, and there are a host of other alternatives. A *strange attractor* is one in which the system follows a chaotic trajectory, but nevertheless forms an overall pattern, with the trajectories being bound in a limited area of phase space, usually recognisable as a pattern or 3D shape. The well-known attractor shown in Figure 1a was first described by Lorenz (1963) and is now commonly referred to as the Lorenz Attractor. Lorenz (1993) describes the global weather system as having such an attractor: despite it being difficult for meteorologists to accurately predict the weather more than a few days in advance, we do know that on average it will be warmer and drier in the summer than in the winter in the UK.

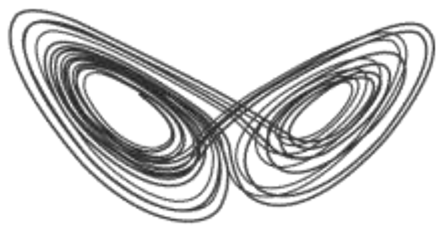

Figure 1a – A Lorenz Attractor

However, we must be very careful in labelling attractors and chaotic systems. Whilst aspects of the global weather system can be described by mathematical formulae, there is no set of equations which are able to accurately describe the weather system as a whole. Therefore the conclusion that the weather is a strange attractor is drawn only from analogy between mathematical models and our experience of the weather. This is important as when social

[2] Animation allows a 4th dimension to visualisations and colour a 5th, but a phase space can have any number of dimensions.

systems are described as strange attractors we must recall the analogical leap that is being made and judge the validity of such a relationship (see 1.2.2). The equations used to make weather forecasts deal with structures on the scale of tens of kilometres and by necessity omit detail in order to enable computation. So the sensitivity of the weather to initial conditions is seen within the mathematical approximations we have to it. Lorenz (1993) is careful to discuss the weather as:

> "an example of an intricate dynamical system, and present the case for believing that its irregularities are manifestations of chaos." (Lorenz, 1993, p79)

He draws on the success of mathematical simulations in predicting the weather over a few days and the sensitivity of these to initial conditions to conclude that the weather must also contain this initial sensitivity and thus be chaotic. This inductive step is sound within the field in which Lorenz is applying it but must be brought into sharper focus for the purposes of this study.

In Lorenz's definition of chaos, quoted earlier in this section, he deliberately excludes the external influences acting upon the system, and yet he refers directly to the action of the sun in stimulating changes in the weather system (Lorenz, 1993). Whilst this does not refute his assertion that the weather is a chaotic system[3], it does illustrate the differences between a mathematical simulation in which the action of the sun is expressed by formulae, and the real system in which such influences cannot be precisely defined. It is the extent to which a system can be defined by mathematical equations that will form part of our distinction between chaos and complexity.

1.2.2 Chaotic Systems vs. Complex Systems

Scientists will usually be dealing with one particular system which is well defined mathematically or physically and as such do not rely upon precise labels for those systems. As far as definitions go therefore, complexity is the term used to describe systems in which individual aspects interact with each other and with environment such that behaviour or structure emerges which is not encoded in the interactions alone.

To exemplify this consider the work of Christensen and Moloney (2005) who modelled a simple system in which sand is dropped at random on a flat grid. Initially, a random configuration develops on the grid, but over time a pile will develop and then there will be

[3] Lorenz does not appear to place specific meaning on the term *complexity*, the use of which developed later in the literature.

avalanches as sand falls down the pile. The system organises itself into a 'critical state'[4] in which the slope of the pile is maintained by avalanches. Although the avalanches are seemingly random, over a large timescale they show adherence to simple mathematical laws: the size of an avalanche is inversely proportional to how frequently they occur. This may seem like a trivial system, but the implication is that a system which is driven only by the random dropping of sand organises itself into a critical state and follows simple mathematical rules in maintaining that state. Whereas chaos deals with how seeming disorder can in fact be governed by relatively simple mathematical principles, complexity theory (within the physical sciences at least) deals with how patterns emerge from the interaction of individual bodies or agents, only responding to their local environment.

Osberg (2005, p.153) notes that in a chaotic system the iterated formula determining its development remains constant. In complex systems however the rules or algorithms change over time. Cilliers (1998, p.9) argues therefore that the algorithm which defines a complex system cannot be simplified without a loss of detail in the system. Due to the sensitivity of a complex system to changes in its variables/elements, a model of such a system can be no simpler than the system itself. However, as Osberg, Biesta & Cilliers (2008, pp. 218-219) caution, finding rules in a model should not be mistaken for evidence that there are rules in the complex system being modelled.

Reconsider Christensen & Moloney's (2005) sand grain system. There are rules describing the evolution of the system: a grain of sand is dropped at random; if the angle of the slope is greater than a critical angle then the grain will move; if this movement causes another slope greater than the critical angle then another grain will move; this will repeat until the system has 'relaxed'. This whole process is then iterated for another grain of sand being dropped. Whilst there are rules for the system, the shape of the sand pile and position of each grain of sand is not described by a set of elegant equations, and the outcome of an iteration will depend upon the state of the system prior to it. Describing the system by the iterative process alone does not allow a complete description of the sand grain system; it instead provides a description of all possible sand grain systems. A model run again using the same algorithm will produce a different sand pile. In order to fully understand the system we need to know not only how the system evolves, but also the exact state of the system at that point[5]. This is why Osberg (2005, p.154) notes that the history of the system is built into its structure. Chaotic

[4] Whilst 'critical states' might be seen as related to the term 'attractor', the former is manifest in a physical system whereas the latter is a mathematically determined pattern.

[5] It is possible, but unlikely, that a system will come to exactly the same state by different processes.

systems are those determined wholly by mathematical equations or algorithms. A die hard determinist may argue that the whole universe is determined by mathematics which is simply too complicated for us to understand. However this is brought into question by quantum physics and by Prigogine's interpretation of complex systems (see 1.2.4) which both support the indeterminacy of complex systems.

The role of the 'environment' is also important to complex systems, whereas chaotic systems are determined by the 'internal' dynamics, as the earlier quote from Lorenz (1993) shows. Complex systems respond to the environment in some way. In the sand pile it is gravity and the stickiness of the sand that determines the response of the pile, but the pile is 'driven' by the addition of new sand grains, and responds accordingly. Complex physical, chemical and biological systems are all driven by some gradient in the environment, be it concentration of solutions or the temperature gradient provided by the sun. The system adapts to these external influences.

This difference between complex and chaotic systems can be illustrated by returning to Lorenz's suggestion that "we are more or less forced to conclude that the atmosphere itself is chaotic" (Lorenz, 1993, p.102). Drawing on the discussion above we see that it is actually our models which are chaotic; the atmosphere itself is complex. Lorenz (1993, p.182) discusses the famous conjecture that a butterfly's wings are sufficient to alter the weather, and suggests the evidence is overwhelming, yet on the very same page maintains that there are equations governing the atmosphere. We must assume that Lorenz recognises the difficulty of expressing equations for the behaviour of a butterfly. Even supposing models may be produced in the future which are significantly advanced to consider the effect of a butterfly flapping its wings at a certain time and in a certain space, the crucial point is that we won't have an equation to predict when and where the butterfly will flap its wings. There will always be unpredictable inputs to the system, and we cannot isolate it from these in such a way as to claim the system is determined by equations alone. As such the study of real world systems should be considered complex and not chaotic in nature.

Table 1a summarises the main differences between chaotic and complex systems, as we have defined them above:

Table 1a – Chaotic systems vs. Complex systems

Chaotic Systems	Complex Systems
Determined by dynamic nonlinear equations.	Determined by iterations or algorithms acting locally upon multiple elements.
Self-contained.	Influenced and driven by the environment.
Determinate and reversible.	Indeterminate, with the history of the system being important.
May tend towards attractor states, including strange attractors, or diverge.	Semi-stable structures may 'emerge' which are capable of self-organisation and response to environment.

1.2.3 Emergence

Discussion of the differences between complex and chaotic systems alone does not highlight the key reason that the former are of interest to social scientists. Despite the highly sensitive and unpredictable nature of the elements within complex systems, they often form semi-stable structures, which show discernible patterns of behaviour over short periods of time.

The sand pile will organise itself such that it has a slope with a critical angle, dependent upon the stickiness of the sand, but this can be arrived at in a large number of different ways. This critical angle will then be maintained by random avalanches of varying size. The self-organisation of the system to a state of criticality illustrates through a very simple example the process of *emergence*. Complex systems made of unpredictable elements often self-organise to a dynamically varying state, but one which is nevertheless of a particular structure. This structure cannot be observed on the level of individual elements, but is tangible when the system is observed on some other level.

Whereas chaotic systems develop seeming disorder from simple rules, complex systems develop ordered structures despite being made up of interacting elements which behave unpredictably. The system has an emergent structure. These structures are often able to maintain themselves (through some gradient of energy or matter), and evolve in response to their environment. The structure may then alter in response to a change in the environment, or remain stable in the face of that change. The reason emergence is so interesting is that order appears to come from disorder, or from a previous form of order.

The absence of 'top-down' rules means that the self-organisation of complex systems is a product of interactions in the immediate environment alone. The organisation of ant colonies is one example that has amazed scientists for decades; each ant responds to pheromones in their environment but is ignorant of the system as a whole. The 'ignorance' of elements within a complex system is important to understanding the emergence of such systems, and we must be careful in considering social systems in which participants may be to some extent aware of the system they occupy.

Emergence refers to the development of new patterns, structures, dynamics or characteristics within a system. Emergent properties evolve in an unpredictable way through the interaction of elements within that system and may be conceived of as a qualitative change in a system. As such, complex systems develop through causal processes which cannot be fully described.

Goldstein (1999) provides a useful representation of how the concept of emergence developed historically, which is reproduced in Figure 1b.

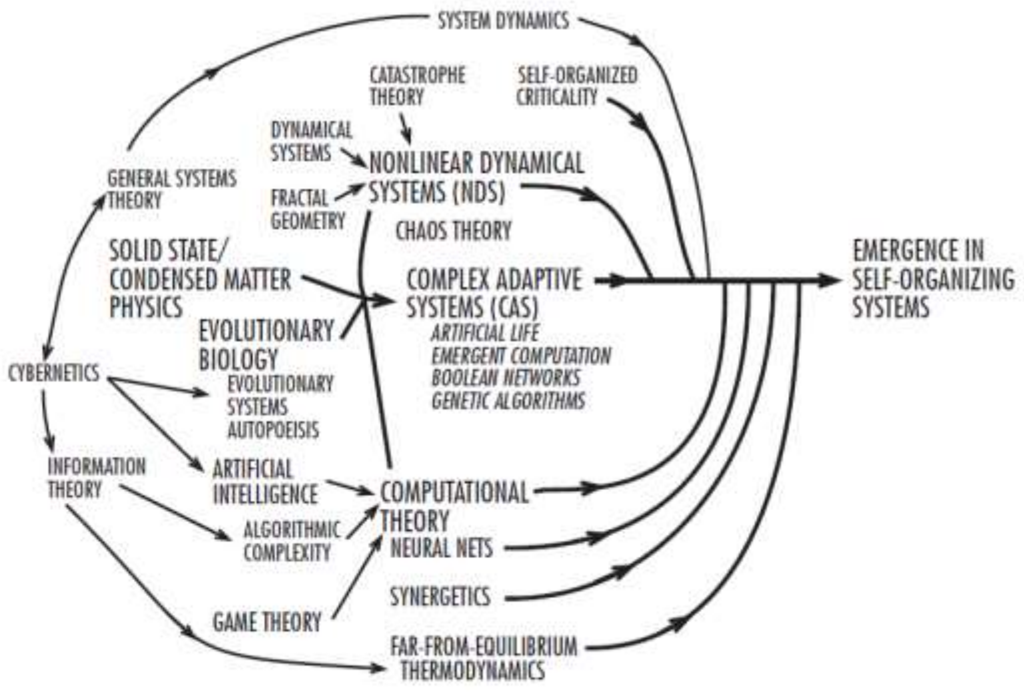

Figure 1b – The Historic Development of Emergence as a Concept, Goldstein (1999, p 55).

Here we see that a number of different disciplines and theories contributed to the development of emergence as a concept, although of course this is itself a model. Nevertheless, we see that emergence has a rich inheritance which ties it to chaos theory and nonlinear equations in mathematics, to evolutionary biology, to equilibrium dynamics, to networks and to many other fields. Whilst it is broadly accepted that emergence developed in the mathematical, natural and computational sciences, its more recent application to social systems has meant that it has gathered other characteristics as it has developed and has become associated with concepts beyond the scope of traditional scientific endeavour. We shall see in Chapter 2 that this is the case in education.

To illustrate the diversity of different concepts, Table 1b shows some of the terminology associated with emergence within different fields.

Table 1b – Concepts Associated with Emergence and their Source Domains

Terminology	***Source Domain***
Bifurcation, control parameter, dissipative structure	Far from equilibrium chemical systems
Self-organised criticality	Physics
Chaos, fractal, attractor, power law	Nonlinear mathematics
Edge of chaos, fitness landscape	Ecological modelling
Distributed representation, small worlds, connectivity	Networks
Genetic algorithm, fuzzy logic, entropy of information	Computer science
Autopioesis	Biology

The difficulty in defining emergence stems from the fact that it is used as a label for the development of novel phenomena in a huge range of systems, and in each if these systems the descriptions of how emergence occurs vary, or in some cases, emergence is simply assumed to happen. In Section 1.3 we will turn to the specific difficulties of defining emergence within classrooms. Firstly however, we will make one further refinement to our working descriptions of complexity and emergence by considering how interactions are *dynamic* and why this makes complex systems unpredictable.

1.2.4 Dynamics & Determinism

Given the difficulty of defining emergence, it is useful to consider further why complex systems are unpredictable over long timescales. In subsection 1.2.1 we described how complex systems are *nonlinear:* multiple factors influence the situation so we cannot attribute a single cause to a particular outcome, and also a small change may have a large effect. Complex systems are also *dynamic*, and this goes beyond simply saying that systems change over time. The use of the term dynamic recognises that there are temporal and spatial influences upon a complex system: it is not just how influences interact that determine how it will change, but also when and where those influences occur. In a classroom therefore, something as subtle as where a teacher stands within a specific part of a lesson may influence the system: their influence is dynamic.

Because the influences on a complex system are nonlinear and dynamic what emerges from them is unpredictable, and this is of key importance in this thesis[6]. However this does not mean that such a system might suddenly jump into a completely different state (Lorenz, 1993). If a car were at 70mph and being controlled by a person with truly random behaviour then they could accelerate or brake at any point, but a car cannot instantaneously drop to 40mph or accelerate to 100mph. This analogy helps us distinguish between complete unpredictability where one moment is independent of the last (as in two flips of a coin) and unpredictability where one of a multitude of things might happen next, but these are *historically contingent*. Complex systems have periods of relative stability, during which patterns may be discernible, yet in the long term they are unpredictable.

Prigogine (1978, 1997) showed that for chemical systems, this unpredictability stems from the tiny fluctuations of microscopic particles that propagate through a system and cause qualitative change on a larger scale. Prigogine argued that it is the fundamental randomness of these tiny fluctuations that make it impossible to predict how the change will occur. If we adopt a view that emergence is the product of fundamental randomness in the universe, as Prigogine claims, then this is different from emergence as the deterministic development of a dynamic system according to both internal and external contingency. In the former, which Osberg & Biesta (2004) denote as *strong emergence*, there will always be a randomness that threatens to alter the system unpredictably. In the case of *weak emergence*, where the system is deterministic, there is in principle the possibility that a system could be controlled if the significant technical barriers to doing so were overcome.

[6] We shall use complexity to argue against learning being characterised as a predictable process (see Chapter 7).

In order to demonstrate the difficulty of explaining emergence in relation to education, consider Osberg, Biesta & Cilliers' (2008) account of emergent curricula (which we will utilise in Section 7.3):

> "The question is how we can represent the behaviour of the system in terms of a set of rules when its output is partially determined by sets of rules to which we have no access (see Cilliers, 2000b, 2001)" (Osberg, Biesta & Cilliers, 2008, p. 219)

This characterisation directly cites Cilliers (2000) who concurs with the argument that:

> "emergence does not involve metaphysical components… we are merely talking about properties that arise because of non-linear, dynamic interactions of which there are so many that we cannot hope to contain all the information involved." (Cilliers, 2000, p. 42)

Cilliers (2000) is concerned primarily with the status of rule-based models as useful but also limited in accurately representing the complex systems at hand. What is of relevance here is that Cilliers characterises emergence both in his earlier works and in his collaboration with Osberg and Biesta as being the product of interactions so numerous and intricate that they cannot be fully described by anything but the system itself. This might be classified as 'weak emergence' as Osberg & Biesta (2004) see it, whereas they elsewhere clearly side with 'strong emergence':

> "complexity science is not wholly concerned with 'weak' emergence. We believe that Prigogine's work in thermodynamics is incompatible with 'weak' emergence and in fact supports a theory of 'strong' emergence." (Osberg & Biesta, 2004, p. 210)

Cilliers is not relying upon fundamental randomness in explaining the difficulty in modelling complex systems, whereas this is how Osberg & Biesta see it. There is tension between whether emergence is to do with chance or to do with the intricate (but ultimately determinate) interactions of the complex system and the environment. This is far from resolved, and Batterman (1991) argues that followers of Prigogine have yet to provide a convincing argument for a random universe at the quantum level. It is still possible that we could reduce such randomness (or probability) to a deterministic position if we had a better theory. Even if this were the case though, it would be impractical, to say the least, to use this theory in everyday life (Richardson & Cilliers, 2001). At the level of classrooms, emergence would be unpredictable either way.

So we do not know whether the universe is fundamentally random or not, but in effect it does not make much difference: the long term trajectory of a complex system is unpredictable either because of sub-atomic randomness, or because of the interaction with an environment that cannot be fully defined, or because of the minutiae of differences already inherent with the system which cannot be accounted for. Of course, it could be all of these reasons or it could be none of them. With our present understanding however, we must accept that complexity theory puts forward a strong case for recognising that, in the long term, complex systems are unpredictable.

In providing a working definition of complexity we have shown that it has roots in nonlinear mathematical descriptions which describe chaos, but in contrast to these descriptions should not be seen as deterministic. Emergence, as the central feature of complex systems, describes the development of novel structures which cannot be predicted in the long term due to the nonlinear and dynamic interactions which take place within a complex system and between that system and the environment, with or without fundamental indeterminacy at the subatomic level. We will now consider why an account of emergence may be attractive to teachers and researchers, before considering the difficulties of developing such an account (Section 1.3).

1.2.5 The Appeal of Complexity Theory in Education

In education, emergence has been linked to many aspects of schooling already, for example school leadership (Morrison, 2002), in managing school systems (Mason, 2008), in relation to schooling and social conflict (Davies, 2004), in relation to action research (Radford, 2007; Phelps & Hase, 2002; Phelps & Graham, 2010) and in relation to pedagogy (Jess, Antecio & Malcolm, 2011; Mercer, 2013; Yoon, 2011). In Chapter 7 we will relate emergence to curricula (Osberg & Biesta, 2004, 2007; Osberg, 2005; Osberg, Biesta & Cilliers, 2008).

So why is emergence such an appealing theory in education? It speaks to the current climate within schools whereby teachers are beginning to question whether learning follows the kinds of pathways that are implicit within approaches such as the National Strategies (DfES, 2003). Such approaches have focused on monitoring rather than developing expertise and capacity (Ofsted, 2010, p. 5) and as such might be said to have assumed a simple, 'linear' relationship between teaching and learning.

However, the tide is turning towards 'evidence based teaching', with government supporting the increase of randomised control trials in education (e.g. Goldacre, 2013) and funding organisations such as the Educational Endowment Foundation (EEF) to the tune of £200m over the next 15 years to undertake research of this kind. Furthermore, there is increasing attention being paid to Hattie's (2008; 2011) meta-analysis which quantifies the 'impact' of aspects of teaching such as class size, the use of inquiry-based teaching, the use of homework etc. Whilst it remains to be seen what influence this focus will have on teaching, it is often simply a sophisticated way of considering attainment: the results that pupils achieve. This is not the same as learning. So when Hattie (2008, p. 133) concludes that phonics instruction has an 'effect size'[7] of 0.6 in developing phonological awareness, reading outcomes and spelling, indicating a very positive impact, he reduces the complexity of an expansive body of research to a single number. Hattie is not alone in such reduction however: the Rose report in the UK (Rose, 2006) resulted in the use of systematic synthetic phonics becoming compulsory in early reading education. However, Wyse & Styles (2007) argue that a vast body of evidence sees phonics as one amongst a range of strategies and is concerned with only a particular aspect of reading. The renewed focus on evidence may be better than earlier attempts by policy makers to determine how learning occurs, as in the National Strategies, but there remains a significant risk of relying on simplistic and *linear* accounts of learning.

Complexity theory offers an account of causation which goes beyond simple cause and effect. The concept of emergence brings with it a rejection of simple causality and predictability, and this is appealing to educationalists because it corresponds to their experience of classrooms. Classrooms and learning are unpredictable, sensitive to context, and do not proceed through simple rules. However, it is far from straightforward to relate complexity theory to a social situation such as a classroom. Drawing on the first sketch of complexity that has been developed within this section, we will now turn to some of those difficulties in order to elucidate the problem that this thesis sets out to resolve.

[7] Effect size is calculated by Hattie as Effect size = [Mean $_{treatment}$ – Mean $_{control}$]/ Standard Deviation

1.3 Defining the Problem

1.3.1 A General Theory of Complexity

Complexity theory appears to offer a way to account for the failure of simple causal explanations and associated technocratic approaches to education. However, it is a double edged sword in that the very account of unique histories, unpredictable development and nonlinear and dynamic causality which holds the appeal, also denies the possibility of mechanisms which are common to all complex systems. We have already seen that different academic disciplines utilise different terminology in relation to complexity. Furthermore, we have seen that complex systems themselves are unpredictable, unique and develop in novel ways such that full descriptions of them are never possible, because we cannot account for infinitesimal differences or randomness within the system or environment, which might cause change.

There are those who insist that for these reasons, complexity cannot be seen as a coherent subject at all. This opposition takes several different forms, for example, Castellani & Hafferty argue that:

> "Social complexity theory is more a conceptual framework than a traditional theory. Traditional theories, particularly scientific ones, try to explain things. They provide concepts and causal connections (particularly when mathematical) that offer insight into some social phenomena…social complexity theory is a scientific framework." (Castellani & Hafferty, 2009, p. 34)

By Castellani & Hafferty's own definition we might still see complexity as a theory containing concepts and causal connections: dynamic, nonlinear interactions leading to the emergence of novel structures. The difficulty comes in that it is not simple to substantiate the theory as each situation will proceed by different causal mechanisms, despite being nonlinear and dynamic.

Such concerns that complexity is not a coherent theory led many to adopt the label of *complexity science* over *complexity theory*, and this can be seen as an attempt by some authors to show that complexity is of greater stature than being a single theory. Drawing on Castellani & Hafferty, Byrne & Callaghan go further in characterising complexity as related to a specific ontological position:

> "when we say complexity 'theory' we mean by theory a framework for understanding which asserts the ontological position that much of the world and most of the social

> worlds consists of complex systems and if we want to understand it we have to understand it in those terms." (Byrne & Callaghan, 2014, p. 8)

So to Byrne & Callaghan, complexity theory contains the assumption that the social world is complex. As we shall see in Chapter 2, there is a large range of ontological and epistemological claims made in the name of complexity theory, many of them at odds with each other. Byrne & Callaghan are at the forefront of *complex realism* (see Section 2.3). However, in linking complexity theory with a particular ontological position, it is fair to say that they are making a claim about what they think complexity theory should be and not what it currently is. There are subtly different ontological positions even from within the complex realism camp. For example, Allen & Boulton (2011) argue that reality 'just is' and that it is our models of it that should be labelled as complex. As such whilst ontological claims are being made in discussing complexity theory, they are not necessarily the same claims.

Furthermore, many of those who might be considered as complexity scientists are not making ontological claims at all. If a modeller feels the phenomenon is best described by nonlinear equations or algorithms, they may develop such a model without labelling it as complex. As such, an implicit ontology will most likely be inherited from the field they are working in. In a sense this is where mathematical and computational modelling is at an advantage over the social sciences, because there is no need to define complexity. One simply develops a model which may or may not be described as complex once it is developed.

Therefore, whilst we can take from Byrne & Callaghan's definition that it has an ontological character, complexity theory must also include the broad range of philosophical claims which are made and models which are developed without an *a priori* assumption of complexity.

In fact, by considering the development of individual models, some authors point out that because every system is unique, we cannot logically consider complex systems as a set of phenomena beyond their not being simple.

> "Under this view a "Science of Complexity" makes no more sense than a "Science of Non-Red Things", since both red objects and simple systems are the exception rather than the rule." (Edmonds, 2013, p. 2)

Edmonds is primarily concerned with modelling social systems in order to develop new understandings of them. So whilst he makes the point that trying to define a coherent science of complexity is futile, like many others he upholds that scientific research into complex systems, with the reduction that this entails, is a worthwhile pursuit.

Here we see that there is a difference between a theory, which has an ontological character as an overarching framework, and individual models, which may have implicit ontological assumptions but which are developed in relation to particular phenomena. In this thesis we shall pay particular attention to models and as such they need defining here (and in the Glossary). We will consider a model as a specific representation of a phenomenon including the understanding an individual has, a verbal or written account, or a mathematical or computational description of the phenomenon. The focus on models as specific representations of the real world will become important when we distinguish our understandings *of* complex systems from our understandings *within* complex systems (see 1.3.3).

In terms of this distinction between models and theories, mathematical *model theory* may be of assistance:

> "A theory admits a variety of models. The theory is not a theory of any one model in particular, but theorizes an aspect of anything that happens to be a model for that theory." (Holdsworth, 2006, pp. 146-7)

Although we are clearly stretching the formal mathematics of model theory in adapting it for our use here, this suggests a theory is constituted by a set of models but also theorises which models are permissible. Under this definition we might allow complexity theory to be the set of all models which describe emergence from nonlinear and dynamic interactions. We cannot assume a bottom-up relationship whereby complexity theory is just a set of models however, because the premises of complexity theory, such as nonlinear interactions and emergence, will also shape new models as they are formed. A teacher, having read about complexity theory, may develop a new model of their classroom, but this model in turn may go on to influence how we define complexity theory.

Therefore in defining complexity theory as it stands, and the models which are permissible within it, we need to examine the ontological assertions being made, as well as the models being used. Thus, Byrne & Callaghan's claim that complexity theory is concerned with real social systems which are complex becomes one possibility which will be scrutinised in Chapter 2. Alongside such realist claims there are reductionist claims that the social world is governed by underlying rules, there are 'post-structuralist' claims that we cannot know how the world works at all and there are claims that the world is socially constructed. Thus the battleground is set for the evaluation of theoretical claims about complex systems. The models that are permissible in describing classroom learning will depend upon the theoretical basis of complexity theory, and this is the primary focus of this thesis.

1.3.2 Importing Concepts

Complexity theory is difficult to define due to the unique nature of each system and the difficulty of claiming simple causal processes which can then be tested. We have also seen that we must consider specific models and ontological positions, as well as the premises which make up the theory. However, there are two further significant issues which arise as we attempt to move complexity theory from the scientific domain to consideration of social systems such as classrooms. In subsection 1.3.3 we will consider the significant challenge of situating our understandings *within* complex systems, as well as considering our understandings *of* complex systems. First though, we shall discuss the difficulties of bringing concepts from other domains into the consideration of social settings.

A significant issue within the educational literature is the misapplication of notions from the physical or natural sciences by importing them into a description of an educational system without critical understanding. As a case in point, take Gilstrap's description of differing complexity perspectives:

> "The 'edge of chaos' philosophy would encourage teachers and administrators to utilize these amplification and dampening mechanisms to help a school thrive at a far from equilibrium level that pushes toward the bifurcation point yet never quite reaches it… Conversely, a pure dissipative structures philosophy argues that transformation takes place by pushing an organization into a chaotic cycle that eventuates bifurcation. In this manner, teachers and administrators would apply positive and negative feedback loops with the intent of causing a bifurcation that leads the organization to a potentially higher level of development... Each philosophy incorporates Prigogine's (1967, 1980) work" (Gilstrap, 2007, p. 59)

It is fair to say that the approaches Gilstrap suggests contain significant misunderstanding of the physics of dissipative structures and that furthermore there is horrible misappropriation of concepts to the field of education. In the above quote we see that chaotic cycles/episodes, and bifurcations are confused but furthermore lead to an unspecified 'higher level of development'. Elsewhere in the paper Gilstrap refers to entropy dissipating from a system and suggests that a bifurcation leads to the advent of two stable systems, showing a misunderstanding of both entropy and bifurcation diagrams. Energy is referred to but there is no questioning of what energy might mean in education and 'stress' is introduced as a concept wholly unrelated to the perturbations that Prigogine talked of. Gilstrap equates equilibrium to stable forms, practices or structures in education and is aligning being far from equilibrium with change. Whilst descriptions such as this are easily critiqued with a basic understanding of physics, they are also potentially dangerous should a teacher attempt to incite a 'chaotic episode' in his or her classroom.

Gilstrap draws from management literature where there are a range of extrapolations from complexity science of this type. For example Overman (1996) advocates managers loosening their tight control procedures to allow change to occur and McMillan (2008, p. 124) suggests that once provided with a strong vision for the future a company should be allowed to self-organise towards this, in the same way that termites organise their societies towards survival. Whilst such concepts can be easily identified as unfounded, there are others which have pervaded the educational literature and which need more subtle critique. One such concept is that of 'the edge of chaos'. Goldstein (2011) argues that the notion that complex systems always organise themselves close to a state in which they would undergo emergence, the edge of chaos, is based upon computational biology in the early 1990s which suggested that this was the case for simulations of evolution. However, many of these studies have since been shown to have been deficient in how they accounted for the process of computation.

This is not a knockout blow for the notion however. Models of avalanches, earthquakes and stock markets suggest that such systems are prone to self-organisation into a critical state (Christensen & Moloney, 2005; Sornette, 2003, 2006). This critical state might be seen as related to 'the edge of chaos' and denotes a state in which change is most likely to occur. In surveying a large range of such models, Frigg (2003) concludes that self-organised criticality (SOC) should not be seen as a general theory:

> "the claim that SOC is ubiquitous is impossible to maintain since most SOC models are gross oversimplifications and cannot in any way be considered realistic descriptions of their target system. Nevertheless, a lot can be learned from the construction and the use of SOC models" (Frigg, 2003, p. 630)

We see therefore that in the case of a concept such as the edge of chaos, there is not a simple misinterpretation of scientific terms but instead there are layers of interpretation from both the scientists who develop models and social scientists who go on to interpret what these models might suggest about a social system. This highlights the danger of attempting to describe a system such as a classroom as complex. Essentially we must draw on models from the scientific literature in order to make tentative models about how a system such as a classroom behaves.

These difficulties are what prompt authors to argue that aspects of social systems can only be related to complex systems as “analogy” (Stacey, 2003a; 2005) or “metaphor” (Byrne & Callaghan, 2014, p.6). This framing as analogy is problematic because it not only rests on the quality of the original models being useful but then on there being a correspondence between those models and the completely different social phenomena they are applied to. As Frigg comments, scientific models are often gross oversimplifications so what might be considered by many as being hard science is no less a process of tentative model making. If such models are taken, as Stacey suggests, as a “source domain” for analogies about social systems we see that we are building models which are themselves inspired by models, but we are furthermore attempting to in some way justify those latter models without reference to the social systems at all. When we make a statement about learning in classrooms, we need that statement to be accountable to what we see in classrooms, and not to models of evolution or earthquakes or to mathematical equations (this argument will be develop in Chapter 6).

We have already shown that understanding models as specific accounts allows us to distinguish them from broader theoretical considerations of complexity. We here further the notion that any description of a system should be labelled as a model. This is the case no matter what the system, although of course we will focus on pupils and classrooms, and it is the case no matter whether the description is narrative, mathematical, computational or empirical. With this premise, this thesis will develop a proper account of the roles of models in understanding complex systems and this will provide a basis for evaluating models of learning in classrooms. Indeed, Keshavarez et al. (2010) suggest a number of ways in which schools do not behave the same as complex systems in the natural sciences, for example because although ‘ethos’ can influence action and control, it is not distributed across all agents. As such we also need to be mindful that complexity might not be the best model of classrooms at all.

1.3.3 Extrapolating from Complexity

The characterisation of social systems as ‘analogous to’ scientific models not only masks the need to justify such descriptions but it also results in authors being overzealous in extrapolating insights from their models to the broader world. For example, following Prigogine’s pioneering work in explaining complexity in chemical systems, he also went on to consider how this could be applied to society. Below we can see that just 15 pages after he expresses caution about overstating the significance of his work, he gets caught up in doing just that:

> "we have to be careful; human beings are not dynamic objects" (Prigogine & Stengers, 1984, p. 298)
>
> "We now know that societies are complex systems involving a potentially enormous number of bifurcations exemplified by the variety of cultures that have evolved in the relatively short span of human history" (Prigogine & Stengers, 1984, p. 313)

Whilst it should be recognised that Prigogine & Stengers did not adhere to the specific use of the term complexity that we do today, these quotes illustrate a tendency to stray into discussion of social systems, despite an awareness of the pitfalls of this. Kohler proposes that:

> "Because we see a fit between some of our actions and the understandings that we have built about the world, we are tempted to assume that all our actions, and those of others, are generated by those meanings and are (literally) meaningless without them." (Kohler, 2000, pp. 5-6)

This might be reframed in the adage that if the only tool you have is a hammer, then every problem looks like a nail. In education, this manifests as authors reconsidering existing notions of learning in light of complexity, as we do in this thesis. But again we must guard against unsupported extrapolation.

Several educationalists link emergence from interactions in complex systems with Vygotsky's (1978) account of learning through social interaction (Davis & Sumara, 2006; van Geert, 2000; Brown, 2013). As a case in point, Jörg (2004, 2009) argues that Vygotsky's later work laid the foundations of a "generative theory of development" focused upon reciprocal interactions in classrooms. This, Jörg claims, allows for a "rethinking" of education as "an emergent process essentially developing without a central agency, and, therefore beyond real control" (Jörg, 2009, p. 10). Jörg moves from an argument about why we do not understand the role of interactions in the classroom (because they are complex), to arguing that the study of interactions approaches "a new, complexity science of learning and education" (Jörg, Davis & Nickmans, 2007, P. 145). Importing terms from complexity is not enough to develop a new science: we need new models. The appeal to a general form of complexity allows authors like Jörg to argue, in a seemingly reasonable way, for approaches that "generate" or "harness" complexity, or suggest that we can develop a "full understanding of complexity" or that "part of the answer seems to be in developing the art of stepping outside the system we are in, and taking a different view: a view from the outside." (Jörg, 2004, p. 129). Yet complexity is neither something that can be generated or harnessed, or that we can step outside of.

Furthermore, in direct response to Jörg (2009), Biesta (2009) shows that talking about interactions is far from talking about a science of education. Education involves purpose, process and content (Osberg & Biesta, 2008). Because complexity theory shows how interactions lead to the emergence of dynamic structures, it is reasonable to suggest that interactions are important in understanding dynamics within the classroom. However, we cannot jump from this suggestion to making claims about how learning occurs.

The reason for the proliferation of loose models and analogies in relation to complexity in the social sciences is the lack of a sound theoretical framework in which to evaluate and critique models. The concepts associated with emergence in Table 1b are consistent with the scientific domains that they are rooted within. Only recently have there been attempts to understand and define the theoretical basis of complexity theory within the social sciences and there has been very little theoretical discussion in education to date. Thus, by establishing a theoretical basis for complexity in education, and positioning models of classrooms within that framework, this thesis aims to provide a basis for the development of models which are appropriate to classroom learning (this is the focus of Chapter 6).

1.3.4 Understanding Of Versus Understanding Within

We have established that in defining a system such as a classroom as complex there are difficulties in relating specific models to theoretical positions, and there are difficulties in how we utilise concepts from the natural sciences in relation to social situations. These are both issues with how we understand complex systems. However, when we consider social situations as complex we encounter a further class of problems, namely, in how we situate human understanding. Chapter 2 is devoted to exploring how existing positions characterise understanding and there we shall define the term more clearly. Here however we shall take first steps in highlighting why this is not straightforward.

In Section 1.2 we saw that nonlinear and dynamic influences mean that complex systems are unpredictable in the long term. Accompanied with this insight is the realisation that because we cannot have an infinitely accurate representation of a complex system or its environment and/or because there is inherent randomness in the system, we cannot have complete understanding of complex systems. This means that our understandings *of* complex systems are necessarily deficient. This immediately opposes complexity theory to positivist epistemologies which claim we are devising truths about the world. As we shall see in Chapter

2, accounts of complexity theory as pragmatic, post-structuralist, constructionist and realist are all advocated within the existing literature and are at odds. We therefore need to situate our understandings of complex systems in order to find a road towards describing classroom learning as complex. By 'situate', we here mean explore the character that is given to human understandings, the ontological positioning of them and the associated epistemology of how they are related to the world. For example, we will see that agent based models assume a mechanistic process by which humans process inputs according to equations or algorithms (subsection 2.1.2). The ontological assumption of this is that human understanding/processing occurs in the brain as a material process, and that epistemologically agents 'know' about the world through processing information by fixed rules. Of course, this is not an adequate account of human learning, but by exploring the existing descriptions from the complexity literature we will identify the pitfalls and avenues open for describing learning in classrooms.

As well as the difficulty of establishing which theoretical positions are commensurate with complexity theory, there is a sense in which social situations are 'more complex' than natural systems. This is intuitively attractive, because not only are the humans within these systems different to one another and themselves complex, but there is also the necessary inclusion of systems of meaning which we see as particular to humans: language, resources, technology etc. Despite this intuitive justification though, it is difficult to establish what a greater 'level of complexity' might refer to and how we might judge the relative complexity of systems.

What is clear however is that humans cannot be seen as being unaware of their surroundings in the same way as molecules in a chemical system, or ants within a colony. Humans have understandings of their own, which influence the way they act and learn. We have already argued that our understanding of complex systems can only be partial but when we recognise that humans are also part of complex systems we begin to see the problem at hand: humans within complex systems have partial understandings. So humans are neither entirely unaware of their surroundings, nor are humans fully aware of the minutiae of their environment and influences upon it. We also know that human understanding develops in the light of experience and we might define this as learning in the broadest sense.

Our theoretical account must be able to situate (partial) understandings within complex systems and how these change over time, particularly in any account of learning. We must also situate language, mathematics, art and everything else that contributes to human understanding within social systems. This is no easy task and immediately highlights the challenges of describing social systems as complex. We see therefore that in order to consider our understandings *of* complex systems we must also situate our understandings *within* complex systems.

It is easy to see that dealing with complex social systems quickly escapes the realm of traditional scientific endeavour and enters the domain of philosophy. Ontological considerations around language and symbolic meaning relative to the real world rub up against epistemological considerations of how we understand the situations we are part of. In Chapter 2 we shall see that there is considerable friction in existing accounts.

However, what is arguably more challenging still is then turning the realisation that our understandings are socially situated 'in on itself' and recognising that the descriptions we propose of complex social systems must themselves be part of a social system. So this thesis itself must be seen as the product of complex social processes, as indeed are all models. Whereas looking at a chemical system might allow a detachment and a sense of looking 'from the outside', no such privileged positions exists in relation to social systems.

Therefore, before we can develop specific models of learning within a classroom there are considerable theoretical issues to be addressed. As an opening position therefore we will characterise learning as the adaptation of understanding within a complex social system. A Glossary of Key Terms is included at the end of this thesis to aid the reader. Here we are using 'understanding' to denote the perception of an individual which changes with experience. We will later relate this to shared understandings across people and 'concepts' (Chapter 5 and 7 respectively). As was posed in Section 1.1, the issue at hand is how we situate understandings within complex systems. In Chapter 2 we will therefore consider how existing positions account for individual understandings, before considering shared understandings later in the thesis.

We have thus set out the parts of the problem to be addressed within this thesis. Firstly, complex systems as involving the nonlinear and dynamic interaction of influences are difficult to define by their very nature. Each system is unique, sensitive and unpredictable over long timescales. Social situations present considerable further challenges however. The second challenge is that we cannot import descriptions and terminology from other domains because they are likely to be inappropriate in describing social situations which include language, technology, art, music and everything else which characterises humanity. Thirdly, we cannot claim to be outside of the systems we are investigating. As well as recognising that our understandings are necessarily incomplete we must also recognise that those understandings are part of the very systems we wish to describe. Describing classroom learning through the lens of complexity therefore requires first tackling these inherent theoretical difficulties.

1.4 The Thesis

1.4.1 The Destination

Having defined complexity theory and outlined the problems of applying it to classrooms we are now in a position to say something of the solution to these issues. The thesis, that is, the argument being proposed in this work, is that reconciling complexity theory and learning requires the recognition that everything within a classroom has a material basis.

We will show that the issues which plague existing accounts of social complexity stem from failure to situate learning as a material process which takes place within complex, yet material, systems. This failure takes several forms. Drawing upon what we will label *post-structuralist* discourses from the latter part of the last century, several authors have highlighted the dynamic and complex nature of our understandings in relation to the world (see Section 2.2). Complexity supports a view of our understandings as incomplete and as inherently linked to our linguistic and symbolic systems. These systems are themselves complex and as such any simple relationship between the world and our understandings of it is to be challenged. However, the picture developed within post-structuralist accounts is of systems of understanding which are only tentatively linked to the complex world. The separation of the real world and our understandings is problematic and we will show that it stems from dialectical philosophy. A materialist frame allows us to see that our understandings are themselves emergent from the material world: from our brains, bodies and symbolic systems which are part of a single, material system.

We also see a separation between our understandings and the world when both scientists and social scientists describe complex social systems (Sections 2.1 and 2.3 respectively). Often the relationship between a model and the real world is not fully considered. However, scientists who do engage with such issues fall into the trap of situating our descriptions as somehow outside of reality 'looking in'. Whilst they are right to assert the reality of the world, the resistance of complex systems to reduction means that we cannot justify the claim that some models are more accurate than others, because no model can precisely represent a complex system. Furthermore we can no longer sustain the dualist position inherent in scientific modelling; if we separate models and the world then no account can be given for how the two interact. A materialist frame cuts through these problems by recognising that our models and descriptions are also part of the material world and emerge in relation to the phenomena they describe. Our understandings have a material basis in our brains and the symbolic artefacts (words, media, tools etc.) we use.

The final way in which existing positions do not adequately situate learning as material is in adopting the view that the social world is constructed in our minds (Section 2.4). Such a view has appeal because it allows the role of social interaction in constructing shared understandings. However, in considering complex systems we once again come to the issue of how our minds and the material world can be adequately separated, yet be seen as dynamically interacting. Furthermore, by favouring the co-construction of meaning these positions cannot account for how we learn from the material world beyond social interaction. Characterising learning as a material process allows us to see learning from the social world as categorically the same as learning from the material world.

A materialist position is thus able to account for how we learn from the world around us and from each other, yet situate this learning as emergent from the interactions of matter[8]. However, developing a materialist position in relation to social complexity is not as simple (or simplistic) as it may initially seem. Describing ideas, understandings and models as material requires careful explanation and the overcoming of a number of barriers. Firstly, a materialist position must be separated from any connotation of mechanistic or deterministic process. Seeing learning as having a material basis does not necessitate that it can be reduced to that basis. As we have already discussed (in subsection 1.2.4), complex systems are indeterminate because of the importance of nonlinear interactions and sensitivity to context, even if we do not allow randomness at the subatomic level. Thus combining a materialist view with understanding of complex systems escapes the need for determinism and allows novelty within social systems. This will be important in considering how new understandings emerge from context in the classroom.

We shall label the position developed in this thesis as *complex materialism*. The adoption of a new title should not be seen as an act of arrogance however; it is intended to separate the position from 'complex realism' whilst taking much from it, as well as synthesising it with some of the arguments which are classified as 'post-structuralist complexity' in Chapter 2. The adoption of the term complex materialism also allows shorthand reference to the position developed within this thesis.

Complex materialism avoids a mechanistic or determinist view of learning by situating emergence within a materialist frame. Yet there are further barriers to be overcome. In order to sustain a materialist position we are forced to explain how we have shared understandings

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[8] We will define 'matter' in its broadest sense to include energy, forces and other aspects of the 'material' universe (see 3.1.1).

of the world, without relying upon a realm of ideas beyond matter. To resolve this we will explore processes by which we learn from each other and situate these within a materialist frame. This will lead to an account of how we learn from patterns of behaviour and patterns of association through the adaptation of our brains.

Within a materialist frame we must also characterise our models of classrooms as material. The implication within existing literature is that models can be improved by capturing more of the original phenomenon through empirical data (see Chapter 2). However, this is challenged on two counts: firstly, in a complex system any specific detail may become important and thus a 'more complex' model is no guarantee of predicting how the original phenomenon will develop; secondly, the implication is that our models are able to replicate the causal processes of complex systems but it is not clear why this should be the case. The problem of modelling thus becomes an important theme within this thesis as we cannot separate learning within classrooms from learning about classrooms. We will situate models as themselves having a material basis in brains, computers and media, and emerging within social systems (e.g. those of research, policy and practice). Models of classrooms can be linked to what they model by the processes of their genesis and by humans evaluating the similarities between the two. An analogy we shall return to several times is that of a photograph, which models a scene through responding to the pattern of light from the scene at its movement of genesis, but which is evaluated as a useful model by people after the event. Consideration of models thus allows us to see the implications of complex materialism for researching and reflecting upon classrooms.

In a complex, materialist frame we must recognise that our representations of the world are not accurate, complete understandings. Nor are they related to a supernatural world of ideas or predetermined truths. Both our individual understandings and our shared models should be seen as having a material basis in brains, bodies, symbols and tools. They condition and are conditioned by human action and are therefore constantly developing. Thus, the material world and the social world of understandings are one and the same: a world of complex interactions in which history, context and dynamics are ever important. This offers a significantly different view of learning to those which dominate contemporary educational literature.

1.4.2 Signposting the Route

Having outlined some of the difficulties and necessary detours in developing the position of complex materialism, we will here sketch out how the structure of the thesis allows these themes to develop.

In Section 1.2 we developed a working definition of complexity theory and its appeal in education, whilst Section 1.3 began the process of defining the problem addressed within this thesis. There we saw that the uniqueness of complex systems means that we cannot justify importing concepts from the natural sciences in exploration of classrooms. Furthermore, we saw that social complexity presents a series of additional problems in that humans have partial understandings of the world, and that this makes problematic the distinction between understandings *of* complex systems and understanding *within* complex systems. Chapter 2 continues the process of elucidating the problem at hand, by considering existing accounts of social complexity. It is divided into two parts in order to aid the reader. Chapter 2a firstly considers the approaches that scientists use in complex social systems (Section 2.1). It is simplistic to say that all scientists apply a reductionist view and many recognise the limitations of their models. However, human understanding is not adequately accounted for in contemporary scientific models. In Section 2.2 we will then turn to what might be considered as the opposite extreme of accounting for human complexity: linking it to post-structuralist discourse. The consequence of this is that understandings are seen as dynamic, transient and limited, which brings into question whether our understandings can provide accurate representations of the world.

Chapter 2b focuses on 'the middle ground' whereby authors attempt to recognise the limitations of understandings but also recover the capacity to better improve those understandings. In Section 2.3 the position known as *complex realism* is considered, which asserts the reality and complexity of the social world and the utility of social scientific methods in engaging with it. The position of *complex responsive processes*, considered in Section 2.4, instead exemplifies a social constructionist epistemology which sees meaning as generated through social interaction. Chapter 2 thus evaluates four positions: complexity science, post-structuralist complexity, complex realism and social construction in complex systems. Suffice to say here that whilst each of these approaches has merit, none of them adequately accounts for the processes of learning within complex systems.

Through critique of positions within the existing literature we will develop a set of criteria for situating learning within a complex social system such as a classroom. A theoretical position must do three things: it must be able to account for the role that the real world plays in developing our understandings, it must situate our understandings relative to this real world and it must account for how our models and understandings develop within complex social systems. Over Chapters 3, 4 and 5 we will develop the position of complex materialism to meet these criteria.

Section 3.1 provides an initial overview of how complex materialism will resolve these issues and is intended to orientate the reader as to the arguments developed across Chapters 3, 4 and 5. Section 3.2 outlines the 'flat ontology' which is adapted from Deleuze's (2004a [1968]) materialist position and which sees our understandings as part of the material world. This also provides us with first steps in accounting for how experience leads to the development of understanding, that is, to learning. We will see that this immediately has advantages over social constructionist approaches in being able to account for learning beyond social interaction, but also that we can overcome some of the issues that post-structuralist complexity suffers from.

Despite having immediate advantages over existing accounts of social complexity, the materialist position derived from Deleuze in Chapter 3 has two limitations. Firstly, in describing how understanding comes from repeated experiences, Deleuze's account lacks the detail required to be of use to educationalists. It requires explanation of both the specific processes by which learning occurs from experience and an account of how we learn from other people. Secondly, Deleuze utilises a notion of 'virtual causes', which on first sight might be seen as the potential for a past event to influence us in the present, and as a way of replacing the notion of future 'possibilities' (which exist beyond the material world). Whilst we must elucidate the role this notion plays in a materialist framework, we will show that it may be overcome.

Chapter 4 therefore sets out to provide a specific model for how we learn from experience and how this is a material process, whilst not relying upon virtual causes. In Section 4.1 we will draw on existing accounts which link complexity theory to neuroscience and show that the brain can be considered as a complex system itself which adapts to stimuli. Section 4.2 expands this to consider models of how behaviour adapts to experience. We will conclude that whilst we are still some way off understanding the specific details of how our brains and behaviour adapt, it is reasonable to characterise learning as a material process. Furthermore, consideration of brain and behaviour as complex systems provides a concrete account of why our representations of the world cannot be seen as accurate and complete: we develop responses to the world which are distributed across our neural systems. Thus we are able to situate learning as a material process within complex systems without appeal to anything beyond the interaction of matter.

By the end of Chapter 4 we will be able to situate learning as a material process and provide a model for how this involves the adaptation of brain and behaviour. However, whilst this resolves the issues in situating learning within complex systems, it does not adequately describe classroom learning. We must recognise that much of the learning we do is from other people and from the world of symbols and tools that humans have created. Chapter 5 thus takes up the challenge of accounting for how we learn from each other. This is not a straightforward task within a materialist frame because we must recognise everyone's experience as unique and account for our symbolic systems also being dynamic and complex. Building upon the model of learning developed in Chapter 4 we will show that pupils engage with patterns of behaviour and patterns of association which are repeated in classrooms. However, every instance of these patterns is unique in its context and history, and this allows for novel understandings to emerge.

The position we have labelled complex materialism therefore contains a materialist ontology which is developed in Chapter 3, a specific account of how learning can be seen as adaptation of brain and behaviour to the material world in Chapter 4, and an extension of this to describing social learning in Chapter 5. The synthesis of existing models of neural and social complexity with a 'flat ontology', in which our understandings have a material basis, answers the challenges of situating learning within complex social systems.

However, in undermining the capacity to situate understandings as outside of social systems, we can no longer assume that models have a simple correspondence to the world they model. This has implications for describing and researching classrooms. In Chapter 6 we will consider how the position developed in this thesis suggests that our models also have a material basis and are situated within complex social systems. As such, Chapter 6 both meets the criteria of being able to situate our models (set out in Chapter 2), but also sheds new light on how teachers and researchers understand classrooms.

Chapter 7 further considers the implications of complex materialism by relating it to existing discourses around learning. Learning as a material and complex process is opposed to notions around the 'effectiveness' of learning which seek to measure and control learning (Section 7.1). Notions of learning as the acquisition of concepts are also challenged by the account given in this thesis of understanding as emergent from brain, behaviour and context (Section 7.2). Finally, these objections to simplistic and representational notions of learning are brought together in order to both support and extend current critiques of curricula as representing the world (Section 7.3).

The structure of this thesis therefore supports the argument that learning within complex systems is best accounted for through a materialist frame. This chapter and Chapter 2 identify the issues with existing accounts. Chapters 3, 4 and 5 develop the solution: the position of complex materialism. Chapters 6 and 7 consider the implications for describing classrooms and considering learning respectively. Chapter 8, the conclusion and evaluation, will bring together the threads of the argument to show how this thesis presents a view of learning which exceeds contemporary accounts of social complexity and thus meets the focuses of establishing a theoretical basis for applying complexity theory to classroom learning and evaluating its implications.

2a Human Understanding in Complexity Science and Post-Structuralist Accounts

2.0 Chapter Introduction

In Section 1.3 we considered the nature of the problem that this thesis attempts to overcome. Complexity theory challenges the assumptions of simple causal processes and also our capacity to fully predict or explain complex systems. This is because influences interact in a nonlinear and dynamic way and are highly context-specific. This also means that complex systems are difficult to define and this is especially true of social systems in which heterogeneous elements interact, many of which, for example individual humans, might be considered complex entities themselves. As such, the key notion of emergence is yet to be clearly defined within social systems.

However, perhaps the greatest challenge is in recognising that all our understandings are part of complex social systems, so the models we build *of* complex systems, must also be situated *within* complex systems. Our understandings can only be partial and tentative. This chapter will expound the difficulties in describing understandings of and within complex systems by undertaking a critical review of the existing literature. This review is focused on the way that human understanding is characterised and situated in contemporary complexity research.

In subsection 1.3.3 we highlighted the focus upon 'understanding' and how it is 'situated' but it is worthwhile repeating and expanding upon the use of these terms here. The aim of this thesis is to provide a basis for describing how learning takes place within complex social systems, particularly classrooms. As will become apparent however, the existing literature contains a range of different ways to include humans within complex systems. In Section 2.1 we shall see that they are treated as agents who process information and act according to algorithms; alternatively humans are seen as nodes within a network, or as obeying statistical relationships. These accounts cannot be considered to include 'learning' though, because they either reduce human action to fixed algorithms, or don't consider thought processes at all (e.g. when considering how network structure influences people). It is worthwhile exploring these approaches however, because they allow us to see both the 'state of the art' in terms of modelling but also to highlight the deficiencies and limitations of such approaches in relation to considering learning in classrooms. In order to cast our net wide enough to explore contemporary literature we are forced to begin by considering how existing accounts of social complexity characterise human response, thought, or relationships. The term 'understanding' is thus used initially as a broad term to allow discussion of the myriad of ways that humans are considered in the existing literature.

The term 'understanding' has two other advantages however. Firstly, if we define learning as the 'modification of understanding' then this broad definition allows us to include various processes which might not be traditionally labelled as learning, for example, when the relations in a network change over time. Secondly though, 'understanding' is a term which captures not just how the agents or subjects within a model respond but also the nature of the models themselves. For example, we have argued against descriptions of social systems as "metaphor" (Byrne & Callaghan, 2014, p. 6) or "analogy" (Stacey, 2003a; 2005) to systems in the natural sciences. These are accounts of our understanding of complex systems. So the term 'understanding' can be used in relation to descriptions *of* complex systems, as well as in relation to the responses of people *within* complex systems. We will see within this chapter that complex realists (Section 2.3) and social constructionists (2.4) imply a difference between our models of complex systems and their accounts of human understanding within complex systems, whereas pragmatists (2.1.6) and post-structuralists (2.2.4) actively resist such separation.

Similar to the deliberate use of the broadest term possible around human 'understanding', this thesis will rely upon the word 'situate' to denote the character that is given to human understandings by various authors. Again, the separation of ontological and epistemological concerns is denied by pragmatists and post-structuralists, but complex realists favour ontological claims over epistemological claims, and social constructionists might be said to favour the converse. As such the lines between ontology and epistemology are in contention, and the term 'situate' is used as an umbrella term to signify the theoretical character of each position, the exposition of which is the aim of this chapter.

Simply defining the terms 'understanding' and 'situate' hints at the huge diversity of theoretical considerations which will be covered within this chapter. However, the links between contemporary approaches to describing human understandings and their theoretical basis is rarely clear. For example, complexity scientists build specific models, and their theoretical underpinnings often go undiscussed (Section 2.1). Similarly complex realism is associated with social science methodology which seeks to describe complex systems, for example through comparative case study (subsection 2.3.4). The specific approaches used by these researchers colour their ontological and epistemological assumptions. However, post-structuralists (2.2) and social constructionists (2.4) appear to have the converse issue in that the theoretical positions they develop come unstuck when applied to specific cases.

The necessity of starting with broad terminology and exploring both specific models and broader theoretical accounts allows us to approach the breadth and diversity of existing complexity accounts. However, it is worth reconsidering the destination of this thesis (as sketched in Section 1.4.1), as well as how this chapter allows us to approach that destination. In Chapter 3 we will begin to develop the position of complex materialism, which includes a materialist ontology and recognition that humans recognise patterns within the world, including within complex social systems. The job of Chapter 2 therefore is to demonstrate the necessity of this position but also establish why existing accounts are lacking. We will also show why only the proposed position is able to overcome these issues and adequately account for learning within complex systems.

The classification of four distinct positions within the existing literature stems from Richardson & Cilliers' (2001) analysis of the state of complexity science at the turn of the century. Their classifications of "reductionist complexity science", "soft complexity science" and "complexity thinking" have been considerably adapted throughout the doctoral study. The resulting four positions discussed in this chapter are organised into two subchapters in order to aid the reader. Table 2 provides an overview of the main features and issues faced by the four distinct positions explored within this chapter.

By contrasting the issues within existing accounts of human understanding within complex systems, this chapter will establish the need for a better theoretical position. It will show that such a position must consolidate the need for reference to the real world and the recognition that our understandings within that world are dynamic and incomplete. To do so requires an account of how our models relate to the social systems we wish to describe. Such an account must pay attention to the limitations of understanding whilst allowing that the real world has a role to play in this understanding.

Table 2 – Overview of Complexity Approaches and Theoretical Issues

Complexity Approach	Features	Theoretical Issues
Complexity Science	• Generation of models using scientific processes. • Often claims to be 'pragmatic'.	• Inherits positivist terminology such as 'universal laws'. • Models often lack empirical referents. • Theoretical basis of models often neglected.
Post-structuralist Complexity Thinking	• Rejection of representation. • Blurring of epistemology and ontology as mind/matter seen as same system. • Recognition that understandings are transient.	• Rejection of empirical evidence removes criteria for assessing models. • Unable to resolve how people act in complex systems with only partial understandings.
Complex Realism	• Asserts the causal influence of macroscopic social entities, e.g. a classroom, school, society. • Asserts importance of empirical referents.	• Inherits separation of mind and matter. • Aspires to 'more realistic' models which is problematic in complex systems.
Complex Responsive Processes	• Mind situated as outside brain. • Accounts for shared understanding.	• Equating minds and the social is untenable. • Cannot account for learning which is not social.

2.1 Complexity Science

2.1.1 Defining Complexity Science

In this section we will see that scientists situate human understanding in a variety of different ways: as algorithms which determine the response of 'agents'; as following statistical laws; as situated within networks which have causal influence. We will see that the ontological and epistemological assumptions of complexity scientists are often unconsidered, despite claims of 'pragmatism'. As such complexity science provides a range of approaches for exploring human learning but these approaches must be better situated in a sound theoretical position.

To begin defining complexity science approaches, we draw attention to an inheritance from what Morin (2007) refers to as 'classical science'. That is, seeking to define mathematical relationships between variables and then testing those relationships through empirical study. Furthermore, we might classify this as implying a positivist epistemology: that mathematical descriptions supported by empirical evidence are the source of authoritative knowledge about the world. However, there is a performative contradiction in much of complexity science because complexity theory challenges the possibility of identifying precise mathematical relationships: multiple causes operate dynamically such that the emergence of new structures cannot be fully predicted. As we saw in Chapter 1, complexity science developed from mathematical descriptions of chaos and as such there is a tension between the implications of complexity and the positivist framing of its precursors. A number of authors therefore challenge the epistemological and ontological positions implicit in the work of complexity scientists (Richardson & Cilliers, 2001; Morin, 2007; Byrne & Callaghan, 2014).

Richardson & Cilliers (2001) exemplify this with an attack on "reductionist complexity science". Chaos theory has shown that simple mathematical algorithms can lead to highly complicated patterns. Richardson & Cilliers argue that this has led many scientists to the conclusion that when we see complex patterns in the world, they must be caused by underlying rules. Whilst they do indeed identify a logical error, this is a straw man argument. Scientists do not justify their models in this way, as we shall illustrate in subsections 2.1.2 to 2.1.5. Furthermore, Richardson & Cilliers dismiss the possibility of making decisions in daily life based upon equations[9]. Whilst we will see in subsection 2.1.3 that some scientists use terms such as

[9] Richardson & Cilliers dismiss discussion of a 'theory of everything' in physics. They misunderstand that this term does not denote an attempt to explain everything; it is used for attempts to link field theory and quantum theory to explain the behaviour of matter.

‘universal laws’ carelessly, they are referring to statistical relationships, not denoting the kind of blind positivism that Richardson & Cilliers imply.

Morin’s (2007) distinction between *restricted complexity* and *generalized complexity* provides us with a more sophisticated attack upon complexity science:

> “Restricted complexity made possible important advances in formalization, in the possibilities of modelling, which themselves favour interdisciplinary potentialities. But one still remains within the epistemology of classical science. When one searches for the “laws of complexity”, one still attaches complexity as a kind of wagon behind the truth locomotive, that which produces laws. A hybrid was formed between the principles of traditional science and the advances towards its hereafter. Actually, one avoids the fundamental problem of complexity which is epistemological, cognitive, paradigmatic. To some extent, one recognizes complexity, but by decomplexifying it. In this way, the breach is opened, then one tries to clog it: the paradigm of classical science remains, only fissured.” (Morin, 2007, p. 10)

Morin’s historical account identifies that complexity science is proceeding with the techniques and epistemological assumptions of ‘classical science’. The full implication of complexity has not been realised: we cannot hope to find equations which describe the nonlinear and dynamic interactions of a system which has a rich history. Furthermore, complexity challenges reduction within scientific practice by recognising that it is the minutiae of the system, linked in a nonlinear way, which may result in emergence of new structures. Throughout Section 2.1 we therefore support Morin’s call for a *generalized complexity*:

> “But then, what is “generalized” complexity? It requires, I repeat, an epistemological rethinking, that is to say, bearing on the organization of knowledge itself… The knowledge of the parts is not enough, the knowledge of the whole as a whole is not enough, if one ignores its parts… the principle of reduction is substituted by a principle that conceives the relation of whole-part mutual implication.” (Morin, 2007, p. 6)

In relation to human understanding *of* complex systems we must seek a new way to position our models, and recognise that positivist epistemology and reductionist approaches are severely limited. In relation to human understanding *within* complex systems Morin’s notion of generalized complexity suggests that we require an ontological position which situates human understandings by recognising the complex relationships between part and whole of social systems.

Whilst the character of complexity science approaches cannot be fully resolved in such a short exploration, we define them here as those which inherit mathematical, computational and experimental approaches which are reductionist, yet are still being used in relation to complex systems. Recognising that we cannot do justice to the full range of approaches which fit this definition, we will now turn to a few pertinent examples which will allow us to explore how human understanding is situated by complexity scientists.

2.1.2 Humans as Agents

Of particular relevance to this thesis is the class of approaches which situate humans as 'agents' within computational models. Although a social group may be modelled as a single agent (for example classes within a school), or inanimate objects might be included as agents (for example textbooks or computers), of interest here is how human understanding is represented within such models. We will argue that agent based models are yet to provide a coherent approach to modelling human understanding, and indeed the purpose of developing such models is not always clear.

As was discussed in subsection 1.3.3, scientists tend to overstate the relevance of models, or use terminology which obfuscates the model's purpose. As a case in point, Erdi (2008, pp. 144-147) describes the Kermack-McKendrick model in which human ideas are passed on in the same way infections are. Whilst at first glance this does not seem unreasonable, in relation to discussing classrooms we see that the transmission of ideas by physical contact or airborne particulates is a ludicrous misinterpretation of learning. In his introductory text Erdi goes on to describe models for segregation, opinion formation, romantic relationships and drug dealing in order to demonstrate the common themes of such complexity models. These are in effect 'toy models' which are designed to further the practice of modelling, and it is unfortunate that scientists label these models according to what they are reminded of, rather than any reference to the phenomenon denoted. Such models pervade the literature and provide training examples, as well as tools to develop new techniques.

In relation to our focus upon how scientists situate human understanding, it is apparent that in such toy models, human understanding is given a simple mechanistic character. We are returned to Richardson & Cilliers' (2001) argument that scientists are seeking underlying rules to explain complex patterns (see 2.1.1). What toy models show is that simple rules can lead to complex patterns. However, scientists are likely aware that these models are of little use in understanding the 'real world'. Scientists do not always pay due attention to how they model understandings and human action because their primary concern is with the process of modelling.

There are those who go beyond toy models though, and develop more ‘realistic’ models of social understanding. For example, Hill et al. (2011) developed an agent based model of the decision making within a baboon population, with reference to empirical data of a troop of chacma baboons. By modelling range size, daily travel, energy and time budgets, Hill et al. describe how computational actors move within a grid of resources, after ‘voting’ whether they should move on. Research on primate behaviour, cognitive processes and social structures was employed and the model was run with a range of starting conditions to assess the influence of the model variables on the way the computer baboons behaved. The conclusion to Hill et al.’s paper discusses how the coarse way in which the environment is presented, the sampling approach within the empirical data and difficulties in knowing how decisions are actually made led to the disparities found between the empirical data and modelling output.

This example of a social model, albeit it with baboons, exemplifies the interdisciplinary approach coveted within complexity science. However, this leads to difficulties in ascertaining what the model is for. There is certainly an aspect of the model being developed in order to refine modelling processes, forming the motivation for the involvement of a computer scientist. The authors also argue that the model adds to a “growing body of evidence” about how decisions are made in primate societies, but there are no stronger arguments presented for what is actually learned about baboon behaviour, despite the other two authors being a biologist and an anthropologist. It is clear that the authors are stimulated and engaged by the problem and have attracted funding by a body equally engaged with it.

There are two key issues at hand therefore. Firstly, how does such a ‘realistic’ complexity model situate social understandings *within* complex systems, and secondly how does it aid our understanding *of* complex social systems? In answer to the first issue we see that the understanding of the baboons above is given a mechanistic character: they respond to the environment (including their energy ‘needs’) and to each other and take action. The decision making process is determined by sophisticated algorithms. If we allow that primate brains are themselves complex (see Chapter 4) then we see that this is a considerable reduction of the processes involved and denies the importance of individual histories and relations. As to the positioning of understanding within this model, it is evident that the decisions are seen as emerging from real processes within the brain in relation to the environment. Within the theoretical position developed in Chapter 3 we will uphold this characterisation of understanding and decision making as a material process.

Given that the algorithms used in Hill et al.'s model are not able to recreate the complexity of a primate brain, we also approach our second issue: what do such models tell us about complex social systems? In this case what does the model tell us about baboon decision making and troop behaviour? To clarify this we must examine the epistemological claim that being able to recreate empirical data within a model tells us something about how the real world phenomenon actually behaves. So in the case of the baboon troop, the researchers invested time in considering how the baboons might make decisions to move within their territory. The implication is that if they had been able to recreate the empirical data then the scientists would be able to say something about the way that baboons actually behave. Because they didn't recreate the empirical data, the scientists themselves conclude that they do not know enough about these processes.

The scientists appear to be implying that this sort of model allows the generation of hypotheses about the causes of behaviour, from the empirical data. This is a tall order in a complex system because we know that even if there is the slightest difference between the model and the phenomenon being modelled, then they may proceed in very different ways. Effectively, modellers are attempting to backwards engineer causes from observations.

This is the case in the modelling of a range of human systems. For example, 'complexity economics' (Cristelli et al., 2011; Arthur, 2013) is concerned with demonstrating that simplistic, macro-level economic models have failed and that agent-based and evolutionary models may provide better understandings. In anthropology, Kohler & Gumerman (2000) present a volume in which 'artificial societies' are used to explore social situations such as Mesolithic foraging, Anasazi cultural change, the impact of raiding on settlement patterns in Oaxaca, Mexico and the political impact of marriage in Polynesian society. Kohler (2000) makes the case that such modelling allows the possibility of 'generative social science', in which we are able to provide possible mechanisms for the evolution of norms, values and social institutions by modelling them. Furthermore, modelling may allow augmentation of traditional social science, for example in replacing the often simplistic reliance upon social variables, such as industrialisation, wealth or population density, with more sophisticated understanding of social interactions and coevolution. It may also, Kohler suggests, allows social scientists the capacity to deal with differing levels of analysis: genetics; relationships; behaviour; social structure and understand how they interact.

Kohler's arguments highlight the potential benefits of agent based modelling, but he does not fully explain how these models relate to the phenomenon being modelled. Byrne & Callaghan (2014, p. 40) argue that 'generative' modelling often results in "abstraction without any empirical referent". This is the case with toy models, which have the purpose of developing techniques, but Byrne & Callaghan also take aim at large scale projects which produce models to explain existing models[10]. Models such as those above pertaining to baboon troops and Polynesian societies are related directly to empirical data. However, such models seek to generate understandings about social systems without having a clear epistemological grounding. The scientific domain, of which complexity science is a subset, appears to have a certain 'internal consistency' in that scientists themselves define the problems that they investigate. Within the existing complexity science literature this manifests as agent-based models which generate new understandings, but not necessarily understandings of phenomena in the real world.

We need to better situate the relationship between models and what is being modelled, before we can apply such techniques to classroom learning. Exploration of agent-based models has therefore shown us that it is possible to situate understandings and actions *within* complex systems as being part of the material world. However we have questioned the reduction to mechanistic processes which models rely upon. In relation to our understanding *of* complex social systems therefore we see that agent-based models are able to generate new understandings, but these understandings need to be related to the phenomena being modelled through clear epistemological consideration.

2.1.3 Humans as following Laws

We saw in subsection 2.1.1 that Richardson & Cilliers (2001) deny the possibility of equations being able to describe our everyday lives. In the light of our discussion of agent-based models, this might now be seen as an objection to being able to use equations or algorithms to describe our decision making processes, or the influence of the environment. However, a different class of models exists which seek to describe the statistical properties of the social world through equations. These models rely upon *power laws*, which are equations that contain exponential terms. For example:

$$f(x) = kx^{\alpha} \qquad \text{[eqn 1]}$$

[10] Byrne & Callaghan (2014, pp. 52-55) exemplify this with a large scale project by the UK Engineering and Physical Sciences Research Council (EPSRC) called 'Complexity Science in the Real World' which actually involves a set of sociologists collecting data, from which agent based models will be produced, followed by equation based models being produced from those models.

Where some function f(x) contains a term of x to the power of α. So for example if we consider the volume of a cube v in relation to the length of each side x, we have a power law with k=1 and exponent α=3

$$v = x^3 \qquad \text{[eqn 2]}$$

This might also be considered as a *scaling relationship* because as we increase the length of each side of a cube x, the volume increases as the cube of x.

Zipf's (1932) demonstration that word frequencies in the English language follow a power law such that the second most common word is used one half as frequently as the most commonly used word. The third most common word is used one third as frequently as the most common word, the fourth one fourth and so on[11]. The relevance of such a 'law' to this thesis however is in highlighting that despite the complexity of the English language, words appear to obey a statistical relationship.

More recently, a range of quantities have been explored in relation to population which illustrate such models (Bettencourt, Lobo, Helbing, Kuhnert, & West, 2007). For example, cities with larger populations require fewer petrol stations per person. The length of road surface and electrical cables per person also reduces (power laws describing them have exponents less than 1). This indicates that as cities become larger, the efficiency of these networks increases; more people are able to use the same infrastructure. Human needs such as jobs, housing, water and electricity usage all scale roughly linearly with the size of a city (exponents are approximately 1) as each individual requires these. However, the number of patents, those employed in research and development, the total wages and size of bank deposits within the cities investigated all increase per person in larger cities (exponents greater than 1), suggesting that 'innovation' or 'productivity' increases with size of city.

The consideration of social scaling laws is widespread within the complexity science literature and has been used to consider urban development (Bettencourt, 2011; Batty, 2012), stock markets, (Mandelbrot, 1963; Mandelbrot & Hudson, 2004; Liu et al., 1999; Gabaix et al., 2003), and internet traffic (Crovella & Bestavros, 1997; Rybski, 2004). Furthermore, investigating how power laws vary over time allows consideration of 'critical events' such as crashes in stock markets (Sornette, 2003, 2005; Johansen & Sornette, 2010). Such analysis can also distinguish between word of mouth popularity of bestselling books, which grows steadily, and short spikes

[11] Zipf (1932) proposed an exponent of -1 but Gonçalvesa & Gonçalvesa (2005) suggest that the exponent actually varies by author and genre.

in sales due to advertising (Deschatres & Sornette, 2005). Also, analysis of power laws shows how computer users update their software (Maillart, Sornette, Frei, Duebendorfer, & Saichev, 2011) and the response of religiously motivated attacks to world events (Roehner, et al., 2004).

The salient point here is that despite the complexity of social life, human behaviour can be described by statistical relationships. These relationships can be related to complex systems in a number of ways. Firstly, by recognising that power law distributions denote processes of feedback which are common to complex systems (Miller & Page, 2007: 26-53). Secondly, models suggest that power laws occur when there are networks of interactions within social systems (Barabási & Albert, 1999; Arbesman, Kleinberg, & Strogatz; 2009)[12]. Such relationships between structure and statistical equations go hand in hand with terminology which implies a positivist epistemology:

> "Scaling laws typically reflect, and often reveal, the general principles underlying the structure of a physical problem" (West, Brown, & Woodruff, 2002)

The sense in which such scientists are making positivist claims about the authority of equations or are seeking 'underlying principles' in relation to the social world is pushed further when they publish papers with titles such as "Life's Universal Scaling Laws" (West & Brown, 2004). However, closer inspection reveals that this positivist framing stems from biological studies in which metabolic rate, body mass, circulatory systems, genome length and heart rate can all be described by power laws with similar exponents (Brown et al, 2002) and these similar exponents are described as 'universal' (Goldenfeld, 1992, p. 16). Social properties such as the scaling in urban quantities do not display this 'universality' however (Bettencourt, Lobo, Helbing, Kuhnert, & West, 2007, p. 7303).

Investigation of power laws clearly has an inheritance from positivist science; even the term 'laws' implies that our understanding *of* complex social systems is aimed at uncovering mathematical relationships which 'underlie' the social world. However, a more detailed evaluation shows that scientists recognise that these statistical relationships vary over time and with the exact system being looked at. For example, urban scaling laws may be different in the developing world compared to the cities in the developed world (Bettencourt et al., 2007), and comparison of different 'critical events' suggests that statistical relationships are

[12] We must note the 'internal consistency' of these scientific models once again however, as to generate them hypothetical network models are used to recreate power laws: models are used to support models.

dynamic and therefore can only tentatively represent the social systems they pertain to. Furthermore, Sornette (2009) cautions that many relationships may appear to follow a power law relationship when they do not, and Clauset, Shalizi, & Newman (2006) at length explain the difficulties of fitting power laws to empirical data.

Nevertheless power laws may offer techniques which allow us to describe complex social situations such as classrooms at the statistical level. The issue is that, as with agent-based modellers, scientists who use power laws are not clear about their own epistemological positions and inherit implicit positions from the field they work in. Thus we further the appeal made at the end of subsection 2.1.2 for a sound epistemological position to be established for our understanding *of* complex systems.

How do scientists who consider power laws situate our understandings *within* complex systems though? The simple answer is that they do not situate human understanding as relevant at all. Indeed, the implication is that despite the complexity of social life, we necessarily obey certain statistical relationships. Whilst this fits well with a positivist epistemology we see that, as with all statistical models, we are imposing equations on the real world using particular datasets. Whilst we might propose reasons (such as feedback and network structure) for why statistical relations such as power laws fit complex systems, they tell us nothing about human understanding within such systems.

2.1.4 Humans within Networks

Network models graphically represent the relations between members of a social group, but can also include inanimate objects, or even different influences on an individual (e.g. Thagard, 1989). The relations or connections are often 'weighted' to represent the strength of the connection: for example how many times people communicate through an online social network (Scellato et al, 2011) or the transactions between corporations (Iino et al, 2010). More recently, the 'character' of connections is being investigated within networks, for example whether communication between internet users is positive or negative (Gligorijevića, et al., 2013).

As mentioned above, network models offer explanations for the presence of power laws in social settings. Network models can also be used in relation to agent-based models to consider the network of influences upon an agent. However, network analyses are premised on different ontological assumptions to agent-based models and statistical power laws. Wellman (1988) argues that network analysis has a theoretical content beyond being just a methodology in that relations or connections come to define the system. He highlights the assumption that relations are more important than 'attributes' such as age or gender. Along these lines, Carolan (2014) proposes that network analysis is premised upon an ontology of 'relational realism'. This has synergy with the concerns of some social theorists:

> "what exist in the social world are relations – not interactions between agents or intersubjective ties between individuals, but objective relations which exist 'independently of individual consciousness and will'" (Bourdieu & Wacquant, 1992, p. 97)

The ontological assumption that relations or connections are real entities has implications for how human action and understanding is characterised. Byrne & Callaghan argue that:

> "these [network] tools in and of themselves do not have predictive capacity because those that do attempt prediction necessarily assign causal power to connections, deny agency, and do not have the capacity for coping with emergence. When social network analysis is deployed as part of a multi-method approach to researching complexity it can be very useful indeed. On its own it can generate descriptions but cannot get beyond this." (Byrne & Callaghan, 2014, pp. 205-6)

Their argument sets connections and agency as separate however and this needs careful consideration. Much of network analysis is concerned with network structure. In terms of individual agency of people within a network, we might conclude that how they are connected influences the agency they have within the system, whilst accepting that it does not account for individual choice or creativity. The relative interconnectedness of an individual and their 'position' may well influence their learning within a complex system. For example, Paradowski et al. (2012) mapped the network of interactions both within a group of foreign students living in Germany and the interactions beyond that group: interactions with native speakers. They found that those that interacted most within the group did not advance their language scores as much as those with lower inter-group interaction levels.

The connectedness of an individual within a system is likely to have (nonlinear and dynamic) causal influences upon both the individual and the system as a whole. The overall stability of complex systems has been related to the interconnectedness of networks, an insight gained through study of network structure in relation to biodiversity (McCann, 2000; Williams, 2008; Dunne, Williams & Martinezet, 2004), regulatory systems in the body (Whitacre, 2010) and electricity grids (Solé, Rosas-Casals, Corominas-Murtra & Valverde, 2008). Whilst it is not the same as individual agency therefore, there is likely to be a reciprocal relationship between individual connectivity and influence upon a social group as a whole.

Furthermore, beyond analysis of structure alone, contemporary techniques in statistical inference predict how network structure will continue to develop over time and how understandings diffuse throughout networks (Carolan, 2014). As such there are aspects of both prediction and explanation within network approaches.

What is clear from Byrne & Callaghan's objection however, is that emergence need not come about through relations at all. What is missing from network analysis is the complexity of individual minds, the characteristics of individuals (age, gender, skill, confidence etc.) and also the role of the environment. All models are necessary reductions, but network models situate human understandings *within* complex systems as being solely determined by relations, albeit dynamic ones. Network models provide insight, but do not account for the unique histories of individuals and the nuanced responses they will have to the relations they inhabit.

Network analysis assumes the "relational realism" that Carolan (2014) denotes and in so doing shares with agent based models an implicit ontology of causal processes within the real world. In the classroom there would be considerable methodological difficulties in defining relationships between pupils, teachers and objects. For example, body language, proximity, tone of voice, and a whole host of environmental influences would need to be represented. Nevertheless, the implication is that these influences should be seen as real and having nonlinear and dynamic causal power on learning. Network analyses situate understanding *within* complex systems as being influenced by real relations, although the influence is not related to individual thought processes.

In terms of epistemology, again natural scientists themselves rarely make their assumptions clear. However, inherent in the representation of relations is an empirical understanding: that our understanding of relations comes from observation and/or empirical data about the real world. Network models situate our understanding *of* complex systems as through the identification and investigation of relations within the social world. This, like all modelling, is necessarily an abstraction, but provides us with an understanding of how we might situate learners within a classroom.

2.1.5 Understandings in Complexity Science

In subsection 2.1.1 we argued that complexity science has inherited practices and ways of thinking that do not fully recognise the impossibility of precise, mathematical descriptions which describe emergence in social systems. However, this is not necessarily because natural scientists are unaware of the limitations of their models. Instead, we have seen that there are a range of different aims, epistemologies and ontologies at work, often implicitly bound in the field of study rather than explicitly defined. Models are developed as training examples, to develop techniques or, more cynically, just because scientists are interested. We have thus noted a certain 'internal consistency' whereby models are related to other models rather than to empirical data.

In terms of how complexity science situates understandings within complex systems, human understanding and action is afforded a mechanistic response in agent based models, is neglected in power laws and is reduced to relations in network models. However, each approach assumes real causal influence amongst people and with the environment and we can thus say that human understanding is being characterised as part of the real world: a realist ontological grounding. The issue is that each approach reduces human response: to mechanism; to obeying laws; to relations. None of these characterisations of human understanding are useful to educationalists.

Whilst scientific approaches do not adequately situate human understandings *within* complex systems, we have seen that there are also issues in justifying how models enhance our understandings *of* complex systems. Looking past the language deployed by those considering power laws we see that statistical relations vary with context so claims of universal laws are misguided. Agent based modellers appear to be trying to generate hypotheses of microscopic causes by recreating macroscopic phenomena but this is no guarantee of helping us understand real systems. Network models appear to have empirical referents but it is far from simple relating a 'connection' to causal influence. It is clear that the utility of models in relation to real systems needs much greater resolution.

Although there is very little discussion of these concerns within scientific literature, those that do enter into such discussions tend to rely on an appeal to 'pragmatism' (Edmonds, 1999, 2012, 2013; Feilzer, 2012). The appeal to pragmatism is worth brief consideration because links are made within the literature not just to the everyday sense of 'being practical', but also to pragmatism as formal philosophical system (e.g. Davis & Sumara, 2006: 73). Feilzer, argues that:

> "Pragmatism … sidesteps the contentious issues of truth and reality, accepts, philosophically, that there are singular and multiple realities that are open to empirical

> inquiry and orients itself toward solving practical problems in the ''real world''" (Feilzer, 2010, p. 8)

Such a definition has considerable contradiction within it, and the speech marks around "real world" acknowledge that you cannot sidestep discussion of reality and talk about the real world at the same time. Feilzer goes on to propose that it is reality 'as it is experienced' which is important to pragmatists. This fits with Pierce's pragmatist maxim that we should consider the 'practical consequences' of models in order to clarify ideas (Hookway, 2013; Haack 1976).

A closer look at pragmatism, as a school of thought, reveals that it does not attempt to sidestep philosophical claims at all though. As Feilzer admits, pragmatists are "anti-dualists". Rather than arguing for a subjectivist position in which knowledge is purely in the mind, or an objectivist position where knowledge is about a separate real world, pragmatists question this seperation:

> "The mind-world scheme does indeed only offer two options: objectivity or subjectivity. The crucial question, however, is not which option to choose. The far more important question is whether the mind-world scheme is itself inevitable or whether it is possible to think about knowledge and reality in a different way, starting from different assumptions. John Dewey's theory of knowing does precisely this. ... Dewey put forward a framework which starts with interactions – or as he later preferred to call it: transactions – taking place in nature and in which nature itself is understood as "a moving whole of interacting parts" (Dewey 1929, p.232)" (Biesta, 2011, p.5)

Biesta (2011) explains further that Dewey's 'transactional theory of knowing' situates learning as arising from the interaction of an organism with its surroundings. The very notion of epistemology is brought into question because having knowledge *of* the world implies some seperation of world and mind. Whilst appeal to pragmatic concerns might be seen as a way to sidestep philosophical discussion, Dewey, a key name in pragmatism, is actually developing a particular philosophical standpoint. He brings into relief the seperation of mind and matter and proposes that our understandings, including our models, should be situated within the natural world. As Olssen suggests:

> "Dewey's approach conceptualises part and whole in a dynamic interaction, posits the learner as interdependent with the environment, as always in a state of becoming,

> giving rise to a dynamic and forward-looking notion of agency as experiential and collaborative." (Olssen, 2011, p. 19)

Dewey's form of pragmatism at least, develops an account of solving problems through being part of the material world. It is therefore far from inert in theoretical terms.

Davis & Sumara (2006, p. 73) argue that the pragmatists pre-empted the 'sensibilities' of complexity theory, and we will explore their account in the next section. We can here support Castellani & Hafferty's (2009) claim that complexity science as a field is itself a complex system: there are a range of interacting practices and approaches, a micro-diversity of epistemological and ontological assumptions and self-referential elements. By recognising that human understanding is situated within complex systems in this way we explain why models may be coherent with other models rather than clearly relating to the empirical world.

However, explaining is not justifying. Having seen that pragmatism does not allow us to sidestep theoretical concerns at all, we maintain the argument within this thesis that a sound theoretical basis is needed in order to situate human understanding in social systems such as classrooms. What has been brought into question is the separation of ontology and epistemology, and this will form the starting point for considering what we will label as post-structuralist complexity thinking.

2.2 Post-structuralist Complexity

2.2.1 Complexity Thinking

The presentation of different modelling approaches in Section 2.1 showed that complexity scientists operate without clearly defining their epistemological and ontological assumptions. We are now in a position to recognise the way in which Morin (2007) described such approaches as 'restricted complexity'. Agent based, network and power law models proceed with the tools and many of the assumptions of 'classical science' in that they seek to uncover mathematical relationships which describe complex systems. In line with Morin's call for a 'generalized complexity', Richardson & Cilliers propose that there is a category of complexity theory approaches which they label as 'complexity thinking', and which involves:

> "a fundamental shift in the way sense is made of our surroundings is necessary: the limited and provisional nature of all understanding has to be recognized." (Richardson & Cilliers, 2001, p. 8)

Although Richardson & Cilliers (2001) proposed that complexity thinking was the least well represented within the literature, it now accounts for a large proportion of educationalists who consider complexity theory today. These authors claim that the shift in how we position our own understandings is to be achieved by aligning complexity theory with a *post-structuralist* position (Davis & Sumara, 2006; Cilliers, 1998; Osberg & Biesta, 2004).

The term post-structuralist is used here to denote authors who label themselves as such, and who are labelled as such by others. We will develop the use of the term more clearly in relation to the accounts of Davis & Sumara (2006) and Cilliers (1998, 2005) in subsections 2.2.2 and 2.2.3 respectively. However, it is worth outlining here the lineage from Saussure, to Derrida and in turn to Davis & Sumara and Cilliers. Saussure[13] criticised linguistic theories based around rules which relate phenomena (the signified) to the labels we have for them (signifiers). Instead of there being a direct correspondence between the two (representation), Saussure proposed that the meaning of a signifier is determined within a system of interrelated signifiers. For example we only understand what a table is on account of its relation to a chair, a stool, a bench but also in relation to a tree or any other object. Although Saussure focused upon linguistics his work was interpreted as being about meaning and this was taken up by several continental philosophers, including Derrida.

[13] Saussure might be described as a *structuralist* as he developed a theory of meaning as arising within a system of relations. Derrida is thus a *post-structuralist* in the sense of following Saussure but questioning static relations.

We see that with Saussure's work we are already relating meaning to a system of interrelated terms. Derrida added 'movement' to Saussure's work by arguing that the meaning of a term is not just related to a system of terms but that those relations are dynamic. Thus there can never be any complete resolution of them, only temporary and provisional meanings which emerge dynamically. Davis & Sumara and Cilliers see parallels between Derrida's system of meaning and complex systems because both are dynamic and emergent, and both are incompressible in the sense of not being reducible to rules.

We will now turn to how Davis & Sumara situate learning within classrooms, and will argue that there is a tension between the way that they situate learning within complex systems and their resistance to accounting for how we understand those systems. In subsection 2.2.3 we will consider Cilliers' more thorough linking of complexity and post-structuralism, whilst also highlighting some of its limitations.

2.2.2 Complexity Thinking as Analogy – Davis & Sumara's Approach

Davis & Sumara's (2006) account of classrooms as a complex system has been drawn on by teachers and researchers (e.g Sinclair, 2004; Sullivan, 2009) and is influential around the world. They situate learning as being within a nest of complex systems (see figure 2a) in which different levels of analysis can be seen as developing over different timescales.

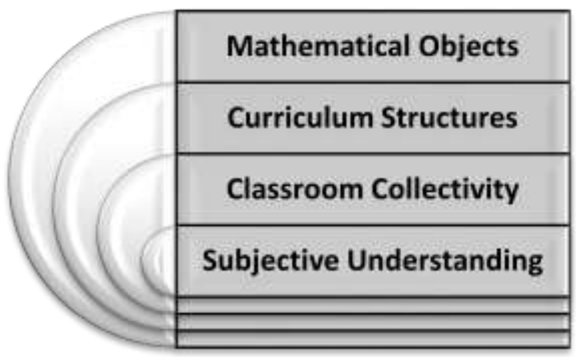


Figure 2a – Nested Complex Systems of School Mathematics as represented in Davis & Sumara (2006, p. 91)

Subjective understanding can be seen as interacting with the classroom as a whole, with the curriculum and with slower changes in the subject itself, for example the field of mathematics. They propose that mathematical 'objects' and curriculum structures are often seen as 'objective knowledge' but are in fact dynamic themselves. Davis & Sumara use this to undermine accounts of learning as the direct relationship between objective knowledge and the subjective understanding of individuals. They furthermore explain that the boundaries of these systems are not clear cut.

It is evident that Davis & Sumara situate human understandings as within nested complex systems and they use this as a frame for critiquing accounts of learning as focused upon a particular level of analysis. For example, they suggest that Piaget's well known educational theories are concerned with the 'self-organisation' of cognition and that Vygotsky's theories were concerned with the interactions between the social world and individuals; therefore "Different processes are at work, and different concerns arise at the two levels of organization" (Davis & Sumara, 2006, p. 65). They propose that by "level-jumping" teachers and researchers can frame different discourses as pertaining to different levels of analysis. However, they note:

> "Complexity thinking is not a metadiscourse that seeks to offer totalized explanations, but an umbrella notion that enables researchers to note profound similarities across a diversity of phenomena" (Davis & Sumara, 2006: 127)

This is where the cracks begin to appear in Davis & Sumara's account however. Whilst they claim that complexity thinking is not a 'metadiscourse', they use it to suggest that complexity has shared 'sensibilities' with a range of positions, including constructivism, cognitivism, phenomenology, psychoanalysis, structuralism, pragmatism and post-structuralism. Yet no umbrella notion could admit these different accounts without recognising the clear tensions between them[14]. Whilst there may be a lineage between these positions and complexity thinking, the issue is that complexity thinking is loosely defined in Davis & Sumara's account.

This will be further expounded by considering their account of emergence, which we argued is a key premise of complexity theory (subsection 1.2.3). In the natural sciences emergence is associated with a macroscopic change in the properties of a system and this can be clearly delineated within empirical data or models. However, 'emergence' to Davis & Sumara is associated with interesting events which cannot be traced to an individual aspect of the system but develop from the coming together of people. Davis & Sumara propose that focusing on emergence allows education and educational research to become about "expanding the space of possibilities" (Davis & Sumara, 2006, p. 135). Specifically, they focus on the relationships between internal diversity and redundancy; between neighbour interactions and control; between randomness and coherence. At length they explain these terms and how emergence is to be found between these opposites. This situating of emergence as being 'between' different possibilities seems to stem from the post-structuralist rejection of binary opposites. Take Derrida's account of *deconstruction*: the practice of identifying tensions within a text:

[14] For example, post-structuralism was a direct reaction against phenomenology (Howells, 1999).

> “a kind of general strategy of deconstruction…is to avoid both neutralizing the binary oppositions of metaphysics and simply residing within the closed field of these oppositions” (Derrida, 2002, p. 41)

Rather than relying upon empirical evidence or even a model of how emergence occurs, Davis & Sumara are defining emergence in relation to post-structuralist concerns. As well as lacking empirical foundation, the concept of ‘emergence’ within Davis & Sumara’s text has considerable dangers associated with it if we apply it to classrooms. The deliberate search for and promotion of ‘emergence’ by opening a ‘space of possibilities’ neglects the probability that unwanted events will also develop. Classrooms are carefully controlled by teachers not to stifle pupils but to maintain some control over the learning that takes place. Furthermore control is important for the safety and security of pupils, so whilst Davis & Sumara are not suggesting we have no control, they are not making clear the need to be critical in responding to harmful patterns which might emerge also.

Within Davis & Sumara’s work, ‘emergence’ as a concept takes on a very different meaning to the development of new structures or relations which defines it in the sciences; it is associated with the ‘play’ between binary opposites. This is further evident when Davis & Sumara (2006, p. 153) propose that complexity thinking presents “vital simultaneities” in relation to education: knower/knowledge, of transphenomenality/transdisciplinarity/interdiscursivity, of representation/presentation, of affect/effect and of education/research. Again we see that complexity is deliberately being used as a way of blurring the boundaries. The conclusion seems to be that because complexity theory draws attention to the limitations of understandings and because post-structuralist discourses reject binary opposites then we can see all subjective understandings as valid and all as ‘emergent’.

Whilst Davis & Sumara situate learning as *within* complex systems the issue comes with their account of our understanding *of* complex systems. Davis & Samara admit that whilst they suggest that classrooms and broader educational systems are complex phenomena “the evidence to support such suspicions is sparse and based largely on analogies made to research conducted in other domains” (Davis & Sumara, 2006, p. 79). The issue is that they actively resist attempts to define complex systems. In introducing a range of notions in the natural sciences (e.g. self-organization, scale-free networks, nested organisation), they note that:

> “we qualify the discussion by highlighting the artificiality of any attempt to analyse complexity. The suggestion here is not that complexity can be reduced to these

> aspects, but that these aspects are useful for helping observers identify and make sense of complex structures and dynamics." (Davis & Sumara, 2006, p. 80)

Yet there is an apparent performative contradiction within their text: by saying that complex systems are resistant to analysis they undermine their own claims that classrooms are complex. Davis & Sumara brush over this with appeal to a "reasonable consensus" as to what constitutes a complex phenomenon and the utility of considering different viewpoints.

Davis & Sumara open themselves up to the charge of relativism by offering no account of how learning emerges or even a justification of the way in which systems are complex. They rely heavily upon narrative accounts of particular situations in which they, rather subjectively, conclude that emergence occurred. Whilst narrative accounts should not be dismissed per se, relying upon loose analogy to general aspects of complexity (self-organisation, nested systems etc.) means that very little is actually said about how learning emerges in classrooms. This looseness also means that the differences of opposing accounts are glossed over and substitutes post-structuralist opposition to binary terms for an account of how learning occurs.

In conclusion, Davis & Sumara situate learning as emergent within (nested) complex systems; however they are unsuccessful in describing such systems as complex. By attempting to link complexity theory with post-structuralist accounts they have obfuscated any appeal to the processes that take place in real systems. Whilst these processes are likely unique to each system we should not shy away from investigating and understanding them. We cannot claim that learning is emergent from a nest of complex systems through analogy to systems in the natural sciences alone, or through a loose appeal to the 'sensibilities' of post-structuralist discourses.

2.2.3 Complexity Thinking as Deconstruction – Cilliers' Approach

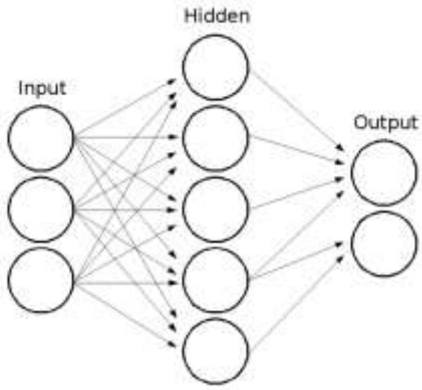
Cilliers (1998, 2005) develops much closer links between deconstruction and complexity thinking than Davis & Sumara do. Whilst not setting out to evaluate deconstruction in its own right, an evaluation of how Cilliers draws on Derrida's work will allow us to expound two arguments of relevance to this thesis. Firstly, Cilliers (and Derrida) reject 'representation', that is, the assumption that our thoughts and language correspond directly to features of the real world. As we suggested in subsection 2.2.1, Saussure's work challenged the simple correspondence of signifier and signified, and Derrida's deconstruction further challenges such a relation. Secondly, both Derrida and Cilliers are concerned with the boundaries of our understanding.

In drawing on complexity science, and in particular neural network models, Cilliers and his colleagues suggest that complexity theory might provide “a modernist argument for affirmative postmodernism” (Richardson, Cilliers & Lissack, 2001, p. 536). By this they mean that complexity theory provides support for post-structuralist accounts of understanding as situated within a network of influences, as well as being bounded in that our understandings are limited. This is of direct relevance to how we might situate learning within a classroom.

Cilliers (1998) forms his argument by first considering the technical issues of representation within neural networks, drawing upon his background as a computer scientist, and then by explicitly discussing the relationships between these arguments and post-structuralism. We will here outline the basis of the argument[15].

A complex neural network may be considered as a series of *nodes* connected by *neurons* such that they are highly interconnected. The use of the term ‘complex’ here denotes that each node is only responding to signals from the neurons it is directly connected to, yet these connections are nonlinear in that multiple nodes are connected to each other, and the signals which travel between them arrive dynamically: at varying times. The system as a whole is able to respond to its environment because the relationships between nodes change over time.

Figure 2b – A simple neural network



In a neural network the relative strength, the *weight* of connections between nodes both determines and is determined by the response of the network to stimuli. Such neural networks adapt to the inputs they are exposed to and so develop responses. However, those responses are not pre-programmed and they could not be seen by looking at the structure of the network. There are no specific representations of objects or actions and therefore no direct correspondence between the structure and the response to the world.

The majority of modern day computers utilise what is denoted as *Von Neumann architecture*, that is, they step through rules and processes in sequence. Even though contemporary *quad core* computer processors divide up tasks so rules can be stepped through by four processors at once, the system is still stepping through a set of rules to respond to input. Neural networks

[15] Cilliers’ account of neural function will also be important in Chapter 4, where it will be the starting point in developing a model of learning.

are different in that they do not have rules and their response is determined by the network structure alone. This means that neural networks are much better at recognising and responding to patterns than traditional computers[16]. The important thing here is that their relationship to the stimuli they respond to is not one of simple representation: Cilliers defines *distributed representation* as the way in which meaning is diffuse within complex networks and thus intangible.

This is the primary site of overlap with Derrida's account and as such we will now turn to elucidating this link before discussing the implications of distributed representation for how we position understanding. Cilliers links the weight of connections in neural networks directly to the notion of *trace*, which is attributed to Derrida.

> "the two terms – 'weight' and 'trace' – can in this context be used to describe each other. To think of weights in a neural network as *traces* (in Derrida's sense) helps to understand how meaningful patterns in a network result primarily from the condition of the weights. To think of traces in language as *weights* helps us to conceive of them not a something ephemeral, but as something actual, albeit actuality that is sparse." (Cilliers, 1998, p. 46)

Cilliers goes on to explain how Derrida's concept of *différance* presents an analogy to the dynamics of a complex system. As a neural network generates a pattern of activity, 'traces' of the activity flood through the system and propagate back through feedback loops, altering both the response of the system and the system itself. Cilliers clearly reads Derrida's work as an explanation for the way in which meaning is distributed across a network and how this calls into question representation, that is, the direct correspondence between the world and our thoughts or social structures. It is not immediately clear whether Cilliers is talking about brains as neural networks, or linguistic systems, or social systems, and we will return to this ambiguity shortly (subsection 2.2.4). However, here we will further consider the relationship between Cilliers' arguments and Derrida's work on différance. Cilliers interprets différance as describing the way in which the meaning of words (more accurately signs) is related to the differences between all other words, but also how this meaning is endlessly differed, both

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[16] Such neural networks have applications in number plate recognition (Draghici, 1997), sales and marketing forecasts (Kuo & Xue, 1999) and predicting the path of pedestrians (Johnson & Hogg, 1996). They can also be used for 'data-mining', whereby patterns are seen in large data sets (Craven & Shavlik, 1997; Castellani & Hafferty, 2009). This is used to discern purchase trends in order to make suggestions in online marketing, or to detect fraudulent transactions with credit cards.

temporally and spatially, in a complex system of meaning. Each word contains a *trace* of all other words because they are interlinked.

There are two points to note about this interpretation of Derrida's work. Firstly, Derrida's works never explicitly defined such a system of différance. Derrida (1968) used différance as part of a word game in which both to differ and to defer were implicated by the use of the French *différer*. This is intended to put the word somewhere between the passive and active, something Cilliers claims is true of complex systems. Différance has further dimensions however.

> "It is not the question of a constituted difference here, but rather, before all determination of the content, of the *pure* movement which produces difference. *The (pure) trace is différance*. It does not depend on any sensible plenitude, audible or visible, phonic or graphic. It is, on the contrary, the condition of such plenitude. Although *it does not exist*, although it is never a *being-present* outside of all plenitude, its possibility is by rights anterior to all that one calls sign" (Derrida, 1976, p. 62) [original italics]

This characterises Derrida's notions of différance and trace as a critique of identity being inherent within an object. Derrida (1978, p. 118) furthermore suggests that trace constitutes presence by relating to both the past and the 'unforeseeable' future.

The difficulty of reading Derrida, which is inherent in the project of critique he undertakes, means that it is equally difficult to evaluate Cilliers' linking of weight to trace and différance to a complex network. Thinking of traces as something actual is helpful, but misses some of the sense in which Derrida considered the term. In a complex neural network, of the type Cilliers considers, weight is a measure of the electrical conductivity of a neuron or of its interconnectivity. Although this weight will change in the future and has changed in the past, due to the diffuse system of changing interconnects, it is hard to conclude "it does not exist" as Derrida claims of traces in the above quote. There is a sense in which Derrida is using différance and trace in a way which is ephemeral, despite Cilliers' attempts to reduce this. Différance is not just a system of differences to other things but also something essential; as Glendinning (2011, p. 62) proposes, what Derrida conveys is a 'self-difference'.

By making the physical system of a neural network analogous to the ephemeral system of différance Cilliers translates Derrida's word play into concepts which make sense outside of continental philosophy and allow it to be married to insights from complexity science. We might thus allow the loss of some of Derrida's initial intention as we seek an account of understanding within complex systems.

The key insight gained from Cilliers linking Derrida's account of meaning to the way networks process information, is that meaning is 'distributed' throughout the network. This is important to our discussion of how we situate understanding within a complex social system for two reasons. Firstly, it refutes a simple relationship between the world and our understandings of it. Our understandings are mediated by linguistic systems which are themselves dynamic and complex. Secondly, because linguistic systems and social relations are networks, humans are situated within such networks. This means that individuals are part of distributed systems and will not be able to fully understand the systems they inhabit; they have access to only a small aspect of the system. We shall return to the limitations of understanding in subsection 2.2.5. However, first we will consider exactly what Cilliers means by distributed systems.

2.2.4 The Ontology of Meaning

Derrida's work was primarily concerned with language and meaning within it. Cilliers interprets the 'distributed' nature of meaning within language as analogous to the distributed processing conducted by artificial neural networks. However, Cilliers (1998) also considers how brains operate in this way, how a (postmodern) society might be considered as a complex system and how scientific knowledge[17] is limited. As with Davis & Sumara's position (subsection 2.2.2), we cannot rely upon analogies to define how a system is complex. Cilliers is not clear about exactly what it is that is 'distributed' or subject to différance in these various systems. He uses the terms 'distributed representation', 'distributed meaning' and 'distributed control' interchangeably in different parts of his work and this leaves ambiguity.

This ambiguity can be further explored if we consider how a classroom practitioner might apply such a critique. What is distributed within a classroom? Control over learning is certainly distributed if we consider that pupils must engage with materials and each other to learn. We might be able to further claim that learning is distributed because the total learning of the whole classroom is not present in any one individual. However, Cilliers relates meaning to identity as well:

> "If, generally speaking, the meaning and function of a component in a complex system is the result of relationships of difference, this would also hold for social systems. In this context then, the notion "meaning" can be used to indicate the identity of the

[17] Cilliers follows Lyotard's (1984) analysis of why science cannot know everything, as part of the 'postmodern condition'.

> system. Thus, the identity of a person or an institution is the result of constrained differences. Identity is therefore an emergent property resulting from the diversity in the system, and not something which exists in an a priori fashion." (Cilliers, 2010, p. 13)

Again, how might an educationalist apply such a notion of identity? We might see the identity of a pupil as defined by their relationships to other pupils, for example a teacher may identify a pupil in terms of their relative attainment or participation within the class. We might also suggest that a class has an 'identity' which is defined not by any single member but by the relationships and interactions between them.

The issue is that by drawing on Derrida's critique of meaning within a language system and applying it to neural networks, brains, science and society, we arrive at a very general critique of representation or identity. What Cilliers offers therefore is a generalisation of Derrida's critique of meaning to claim that within a complex system we cannot consider meaning or identity or control or learning as situated within individual nodes, people or other aspects of the system. In this way, Cilliers' complexity thinking is a form of deconstruction. In Derrida's terms it resists any notion of 'presence' which is inherent in a component of a system.

Derrida's project of deconstruction involves a range of strategies to highlight and challenge assumptions within texts and language itself[18]. However, Cilliers focuses on just one aspect: the constant deferring of meaning and system of traces. He makes this concrete in the relationships between nodes or between people. In relating meaning in language and identity in social and neural systems though, Cilliers (1998, 2001) drifts into talking about them interchangeably. In proposing why meaning/control/identity are distributed we are able to critique representation as the notion of simple correspondence between a neural structure and the world, or between a linguistic signifier and what is signified. However, this general approach to critique, which is also inherent in Derrida's project, does not allow us to relate understanding and the world. Cilliers is claiming that our understanding is emergent in a complex system but also that the systems in the world are complex. However, Bhaskar draws attention to 'epistemic fallacy':

> "This consists in the view that statements about being can be reduced to or analysed in terms of statements about knowledge; i.e. that ontological questions can always be

[18] Derrida (1976, 1978) aims to highlight binary opposites and turn them around, for example by showing that speech is favoured over writing or that male is favoured over female within a text. He also considers the genealogy of concepts within texts.

> transposed into epistemological terms. The idea that being can always be analysed in terms of our knowledge of being, that it is sufficient for philosophy to 'treat only of the network, and not what the network describes'" (Bhaskar, 2008 [1975], p. 26)

Bhaskar is here quoting Wittgenstein (1961, 6.35) in talking about "the network, and not what the network describes", but this takes on a literal character in Cilliers' work whereby he claims that our understandings are emergent within networks of meaning, but also that the world itself contains complex networks. Indeed, in much of Cilliers' work he moves between considering understandings and 'real systems' as complex, without adequate delineation.

In contrast to Bhaskar however, Cilliers (2002) argues that a distinction between the epistemological and ontological is a false one. If we say that systems in the real world are complex then we must accept that our meaning is also constituted by a complex system of relations, as Derrida concludes. As we are subjects in a complex world, we must accept that:

> "the subject is not an independent whole, not a free floating ego that makes "subjective" observations or decisions. It is a complex thing in itself, constituted through the web of relationships with others and the world." (Cilliers, 2002, p. 80)

The tendency for Cilliers to shift between talking about the complex systems from which our understandings emerge, and the systems that understandings pertain to, is born of a belief that the two cannot be separated. Cilliers sees the brain itself as a complex system which adapts through interaction with the world. As such, if we accept that understanding comes from the brain then this is a further nail in the coffin of a distinction between ontology and epistemology.

The insistence on relations to the real world leads writers such as Byrne & Callaghan (2014, p. 57) to conclude that "Cilliers is in practice a very realist sort of post-modernist". Although Cilliers insists on the real world, and the role of our brains in understanding that real world, he does not adequately situate our understandings. The issue is that in wanting to describe a specific situation, such as classroom learning, we cannot rely upon a general deconstruction of identity or meaning. We need to consider the ways in which the systems involved are complex.

We shall return to Bhaskar's arguments in relation to the complex realist position in Section 2.3, and how this relates to Cilliers' position. Cilliers' work rejects a simple relationship between mind and matter, and also between ontology and epistemology. However, by conflating mind and matter he is not able to recognise the differences between systems, and so offers a general critique rather than an account of how systems such as brains and classrooms might develop. We will show in the next subsection that this is because Derrida's approach of deconstruction, which Cilliers relies upon, is unable to make affirmative statements about the world.

2.2.5 Boundaries and Ethics

In developing a critique of there being a simple correspondence between brain, language and world Cilliers sees each of these as complex systems. Not only are the relationships between these systems complex, but if humans are just a small part of a social system then we do not have access to a complete understanding of that system. This can be argued from a network perspective, as Cilliers does, but also from recognition that the influences upon an individual are nonlinear and dynamic within a complex social system.

Cilliers attempts to address the problem of how we situate understandings within such systems by appeal to the boundaries of our understanding. This might be seen as an extension of Derrida's consideration of meaning but the difference between the two accounts is one of degree and of origin. Derrida is not denying meaning but questioning its certainty and there is thus an implication of boundaries to our understanding. However Cilliers makes boundaries central to the discussion of meaning.

> "if an infinite number of interactions have to be considered, the production of meaning will be indefinitely postponed. This, we know, is not the case. Meaning is generated in real time." (Cilliers, 2002, p. 81)

Cilliers (2002) argues that in order to make meaning, there must be boundaries in order to reduce the complexity of the system: we cannot deal with the whole universe at once. He therefore argues that meaning is established relative to the boundaries we impose in our consideration. Boundaries allow meaning by providing reference points but do not deny the possibility of information from outside the system becoming relevant[19]. So he adds to his deconstructive approach the role of boundaries in making sense of the complex systems in the real world, and within which we live.

By adding a notion of boundaries Cilliers attempts to do two things. Firstly, he is suggesting that because people are able to appreciate the boundaries of statements made about the world, we are able to communicate with each other. The implication is that we do not need to

[19] Cilliers (2002) contrasts boundaries to 'limits', which are impermeable in the sense we can know them only 'from the inside'.

deconstruct every statement we make, or understand the full network which gives it meaning: we just need to accept that there are boundaries to the 'truth' of what we are saying. The second purpose of an appeal to boundaries in Cilliers' (2002, 2005a, 2005b) account is to argue against the charge of relativism. Within boundaries, there are statements which are truer than others. Furthermore, we can assess this 'in real time' without reference to an infinite deferral of meaning. Here we see that Cilliers approaches a coherence view of truth: that rather than being determined by simple correspondence to the world, our statements and understandings are coherent within the boundaries of our understanding. Indeed, Cilliers (2005a) warns of the dangers of "academic groupies" and of "vague groupspeak" and concludes that:

> "In some (post-modern) circles a vague kind of chatter, employing a shared vocabulary in an uncritical way, has become acceptable" (Cilliers, 2005a, p. 262)

Cilliers instead advocates concepts which are communicated clearly. This does not mean they have an indisputable identity, they are modest claims, but this does not mean that they must be vague or weak either. Cilliers argues that limits enable knowledge; otherwise we would have to include the whole universe in any statement. However knowledge is also fragile because we exclude something from it which may be important. Complex systems have structure because of their constraints, and meaning in complex systems is similarly bounded but contingent. However, this begs a number of questions about boundaries: how do we define these boundaries 'in real time'? Are the boundaries determined by the individual or socially? To what extent do we have control over them?

Cilliers contends that the way we draw boundaries is necessarily an ethical process (Cilliers, 2004; 1998, pp. 136-140).

> "Whatever we do has ethical implications, yet we cannot call on external principles to resolve our dilemmas in a final way. The fact that some form of ethics is unavoidable seems to be a very important insight from complexity theory." (Heylighen, Cilliers & Gershenson, 2007, p. 17)

Whilst this thesis is not aimed at an ethical understanding of action in complex systems per se, we will explore these arguments insofar as they define Cilliers' positioning of understandings within complex systems.

Heylighen, Cilliers & Gershenson (2007) argue that complexity theory challenges the ideal of a fixed and correct moral code. However, they also contend that complexity theory cannot devise a better moral system, it is instead concerned with the realisation that in every complex social system, we are always making ethical choices. Cilliers (2004) highlights the limitations of both blindly following fixed rules (the 'modernist' project) and conversely of everyone acting on private moral decisions. He draws on Lyotard's (1984) description of power to conclude that in a complex social system any attempt to draw boundaries will disregard those outside of those boundaries. Cilliers (2010) furthers his argument by highlighting the need to respect the diversity which is necessary to the survival of any complex system. This draws on arguments of 'the difference within' which originate from Derrida and are less than satisfactory.

Whilst Cilliers' account of ethical action "resonates strongly with post-structural and Derridean ethics" (Heylighen, Cilliers & Gershenson, 2007, p. 17) it provides a rather amorphous account of how the boundaries of our understanding are recognised 'in real time' and how they determine our understandings within complex systems. Kunneman (2010) argues that there is a tension in Cilliers' work between rejecting any metaphysical or transcendent basis of 'externally imposed' moral codes and the capacity of humans to make decisions at all[20]. In developing a notion of meaning as emergent yet bounded, Cilliers provides no criteria by which to choose one approach over any other. We are not able to adequately situate how we understand and act in the world.

2.2.6 Dialectics and Madness

We will argue here that the issue that Cilliers has in situating understandings is inherited from Derrida. This issue can be seen in Biesta's (1998, 2001) discussion of the role of Derrida's ethics in relation to a just education. He argues that:

> "Just education has to be on the outlook for the impossible invention of the other. The other, Derrida writes, "is not the possible." The other is "precisely what is not invented"." Biesta (1998, p. 409)

Without seeking to explore Derrida's notion of 'otherness' here, we see that 'ethical' decisions made within complex systems are defined in reference to deconstruction. By following Derrida, post-structuralists like Cilliers and Biesta get stuck in a trap of having to accept either the constant deferral/difference of meaning, or they have to construct boundaries which pay attention to the 'other' which sits outside our understanding. Whilst defensible as the practice of deconstruction, this offers no way forward in situating our understandings within a complex system or proposing what we do, let alone what we should do:

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[20] Kunneman proposes a humanist solution, but this rests on Kantian and Aristolean notions of 'good' being defined outside of the system. Furthermore, Smith & Jenks (2005, 2006) show that complexity rejects humanist assumptions that we can use rational or scientific means to fully understand complex systems.

> “The instant of decision is madness, says Kierkegaard. This is particularly true of the instant of the just decision that must rend time and defy dialectics. It is a madness.” (Derrida, 1990, p. 967)

It is unsatisfactory to accept that our understandings within complex social systems are born of ‘a madness’, or that we need to include a sense of what we do not know. The recognition that we can never have complete understanding and that our normative values emerge is in conflict with any attempt to make ethical decisions. Cilliers’ untimely death in 2011 means he did not fully develop his ethical position and we are thus left with a critical position which draws attention to boundaries, but inherits the difficulties that Derrida had in saying anything useful about action. It is worth exploring these limitations further, because doing so reveals that the issue is ontological. As we noted at the end of subsection 2.2.5, Cilliers does not adequately account for how our understandings relate to the real world. We will see that this is because he inherits from Derrida the remnants of Hegel’s dialectic. Highlighting this issue here will point us to the solution developed within Chapter 3, that a materialist ontology is the only way to escape the untenable notion of ‘otherness’.

A full discussion of Hegel’s philosophy lies well beyond the scope of this thesis. However, elucidating features of it will allow us to see the impact it has had on post-structuralist complexity. Although there are many interpretations of Hegel’s work, the ‘traditional reading’ is that Hegel saw the universe as comprising of a single essence or *Spirit*, the development of which involves the resolution of opposites (Redding, 2014; Rosen, 1974). In relation to human thought, which is seen as part of this process, this manifests as the resolution or *negation* of binary opposites. For example, Hegel sees the notion of ‘being’ as definable only in relation to its opposite: ‘nothingness’. These, Hegel argues, can be resolved through a more universal concept of ‘becoming’. In the same way, the concepts of ‘red’ or ‘green’ can be negated through the universal concept of ‘colour’ (Redding, 2014). Whilst we might see Hegel as maintaining a monist position in which the world is Spirit therefore, he sees thought as a process by which we can achieve some universal, transcendent understanding. It is this that Derrida (1968, 1976) takes exception to.

Grebe (2010) examines how the Hegelian notion of negation informed Derrida’s notion of différance and in turn Cilliers’ description of complexity thinking. Derrida rejects the negation or resolution of binary opposites. However, Grebe argues that Derrida does not fully do away with the importance of opposites. We can see this in his notion of traces, which relies on irreducible differences in the world. Traces are continually deferred such that meaning becomes relational with both spatial and temporal dimensions. Cilliers' description of neural networks is also a relational system which draws on Derrida's différance and relies upon a network of differences. Grebe argues that Hegel's dialectic position has been inherited by Derrida and Cilliers and as such we must assess the influence of this upon complexity thinking.

> "In order to see the negativity inherent in the deconstructive practice (and therefore its Hegelian roots), it is necessary to show how Derrida's description of the system, and of the process by which meaning is generated within a system, implies both an inherent instability of meaning, and a "beyond" ("outside" or "remainder") to this system. This transcendental moment in his thought is the source of its critical power, since a trace of the outside and therefore the radically other or new (something which is not implied by the system itself) always enters into the system and disrupts the determination that occurs within." (Grebe, 2010, pp. 104-105)

Derrida's work both attempts to overcome Hegelian dialectics but is at the same time made possible by it. Barnet (1998) argues that Derrida rejects Hegelian negation within philosophy and much of his work is devoted to showing that the resolution of opposites is not possible.

> "conflictuality of *différance* – which can be called contradiction only if one demarcates it by means of a long work on Hegel's concept of contradiction – can never be totally resolved" Derrida (2002, p. 44)

Here we see that Derrida acknowledges the 'long' path from Hegel to différance but refutes the resolution that Hegel's dialectics describe. Derrida 'blocks' the resolution of binary opposites by showing that there is constant deferral of meaning. However, Barnet and Grebe both suggest that Derrida takes from Hegel a way of imagining différance and 'otherness' which is central to the process of deconstruction.

The relevance of such discussion in this thesis is in recognising that Cilliers' account of our bounded understanding within complex social systems owes an inheritance to dialectic metaphysics, albeit one that is 'blocked'. We see that inherent in Cilliers' descriptions are the sense of 'otherness', of something outside of the boundaries, of meaning as being defined outside of the situation at hand. There are thus two issues with post-structuralist complexity as it stands. Firstly, it has inherited an untenable notion of dialectic which means that our understandings within complex social systems must be related to some unknowable 'otherness'. This is highly problematic. Secondly, drawing on deconstruction has replaced a full account of how specific systems interact and how understandings emerge for brain, language and the broader world. We will argue that this can be resolved through adopting Deleuze's ontological system whereby we see understandings as part of a system in which everything is real and meaning is defined in specific contexts (see Chapter 3).

The strength of the post-structuralist complexity account should not be overlooked however. By relating Derrida's account to neural networks Cilliers is able to show that understanding is not situated within an individual person or node, nor is it achieved through the simple representation of the world 'as it is'. This is an advance on scientific accounts of complexity which do not account for their ontological and epistemological basis at all. The post-structuralist account gives us a basis for challenging the separation of epistemology and ontology, which is also challenged by Pragmatists such as Dewey (subsection 2.1.5). On a less philosophical level however, post-structuralist complexity provides a reason why learning is not a simple process: because understanding is situated within a network of connections within the social and physical world. To recover these positive aspects of the post-structuralist account, from the untenable dialectic position it inherits, we require a reaffirmation of what is real and how understandings relate to reality. As such we will now consider whether this might be achieved by the ontological position of *complex realism*.

2b Human Understanding in Complex Realist and Constructionist Accounts

2.3 Complex Realism

2.3.1 The Middle Ground

Reconsidering the orientating frame introduced in Section 2.0, we have already examined what Richardson & Cilliers (2001) denoted as 'reductionist complexity science' (Section 2.1) and the post-structuralist approaches which grew out of 'complexity thinking' (2.2). We now turn to Richardson & Cilliers' third category: 'soft complexity science'. Within this category are those who see the social world as intrinsically different from the material world and thus conclude that complexity can at best be a metaphorical tool to develop new understandings of social systems.

In this thesis we will consider two different positions, both of which can be seen to have grown out of what Richardson & Cilliers called soft complexity science. In Section 2.4 we will explore Stacey's (2003a, 2005) account of the complexity of social constuction. Here however we will consider what is denoted within the literature as *complex realism* (Harvey & Reed, 1996; Byrne, 1998). Complex realism underpins a range of methodological approaches which assert the importance of the real world. Byrne & Uprichard make clear:

> "We are not suggesting a positivist or anti-social constructionist approach to causality here, but rather that materiality needs to be brought back and made central in discussion about social causality." Byrne & Uprichard (2012, p. 124)

Complex realism has a lineage that draws on Bhaskar's (2008 [1975]) *critical realism*, and is then combined with complexity theory by Harvey & Reed (1996) before being most fully developed by Byrne (Byrne, 1998; Byrne & Callaghan, 2014). Harvey & Reed situate complex realism as a 'middle ground' between positivist, reductionist approaches and what they call 'postmodern' approaches to complexity:

> "Such a dynamic realism is capable of sustaining the particularity and plurality of the social world whilst preserving rational canons of scientific understanding." (Harvey & Reed, 1996, p. 297)

The above quote illustrates the desire to allow the dynamic, nonlinear and context-specific nature of social causality but also to preserve scientific rigour. This gives away both the main conjecture of complex realism but also its main problem. By failing to question the "rational canons of scientific understanding", complex realism fails to situate the models it seeks to produce as themselves within complex systems. For all the issues with post-structuralist complexity theory, it does recognise that the models we have of the world are themselves complex entities. Yet there can be little doubt that complex realism is opposed to 'postmodern' discourses:

> "complexity, inductively founded as it is, is not innocent in metatheoretical terms. It does have ontological and epistemological implications, implications which make it essentially part of the realist programme of scientific understanding and inquiry. Moreover, the account it offers challenges in the most fundamental way the postmodern view of the nature of social science and the potentials of its application." (Byrne, 1998, p. 7)

> "In the case of postmodernity we have to accept that the form of social action is absolute social inaction – the disengagement of the intellectual project from any commitment to any social programme whatsoever – bone idleness promoted to a metatheoretical programme." (Byrne, 1998, p. 45)

The second quote relates to the issue we saw in Section 2.2 whereby Cilliers' form of complexity thinking is unable to say anything about action in a complex system. However, the discourse has matured and Byrne & Callaghan (2014) are respectful to Cilliers in particular, whilst maintaining the importance of considering the real word, rather than just focusing on the limitations of understanding. As we saw earlier, Byrne & Callaghan (2014, p. 57) suggest that Cilliers is "a very realist sort of post-modernist", but we might say that conversely Byrne's realism has a post-structuralist character:

> "We are dealing not with labels which exist outside of people and situations, but with the noise, sound and smoke of things in action." (Byrne, 2011, p. 135)

> "It is possible to work with fuzzy set memberships and with multi value rather than binary attributes." (Byrne, 2011, p. 140)

The relationship between Byrne's and Cilliers' position is an important one, both because they are key figures within the complexity literature and also because they give substantial accounts which allow us to see the differences between post-structuralist complexity and complex realism. This difference centres on the way reality is accounted for and we will engage with this shortly. First though, we must lay out exactly what complex realists are saying about reality.

2.3.2 The Mechanisms of Social Systems

Byrne & Callaghan argue that complex realism includes "the ontological position that much of the world and most of the social world consists of complex systems" (Byrne & Callaghan, 2014, p. 8). To elucidate this position it is worthwhile considering Bhaskar's critical realism[21], which Harvey & Reed (1996) draw upon in defining complex realism.

Bhaskar's (2008 [1975]) position asserts the reality of *mechanisms* within the social world, and states that because mechanisms are real they can therefore be investigated through scientific processes. This is similar to the ontological implications of network science (subsection 2.1.4) in that the relations between people are real and can be investigated. Critical realism however, asserts the reality of mechanisms whether they are 'actualised' or not[22]. This leads Srnicek (2007), to argue that Bhaskar inherits a notion of representation in assuming that mechanisms in the world can be represented by science. This is in opposition to the post-structuralist rejection of representation (subsection 2.2.4).

In developing complex realism, Harvey & Reed (1996) argue that social systems are a subset of what we would now call complex systems[23]:

> "the grounding of dissipative social systems in nature and in the dynamics of deterministic chaos demands a materiality interpretation of dissipative social systems" (Harvey & Reed, 1996, p. 206)

However, Reed & Harvey argue that:

> "societies and their institutional activities are constructed by the collective action of human beings, and, thus, are profoundly influenced by the way in which humans subjectively define themselves and their actions. This fundamental difference has already been expressed in Bhaskar's critical naturalist paradigm." (Harvey & Reed, 1996, p. 206)

So the reality and complexity of social systems is asserted by complex realism, but the role of subjective understandings is also recognised. Byrne (1998, p. 37) admits that he does not

[21] We touched upon Bhaskar's position in subsection 2.2.4 in relation to "epistemic fallacy".
[22] Bhaskar's position shares characteristics with DeLanda's (see 6.1.2) in discussing 'tendencies' which are "powers which may be exercised without being fulfilled or actualized." (Bhaskar, 1975, p. 45).
[23] Harvey & Reed refer to deterministic chaos, as well as notions of 'edge of chaos' which have since been challenged during the development of complexity theory, see subsection 1.2.2.

reserve the term 'real' for causal mechanisms as Bhaskar does, but uses it more broadly. This allows Byrne and his collaborators to assert that causality within social systems should be treated as real and discernible, despite being nonlinear and dynamic.

Byrne & Uprichard (2012) consider "useful complex causality" in the sense of how complex realism allows an understanding of causality within complex social systems. Put simply, they argue that agent based modelling is limited because it cannot account for the complexity of relations within and between subsystems, or with systems outside of the one being considered. Likewise a focus on variables at the statistical level neglects the importance of causal interactions within the system. Their solution is to focus on investigating similar 'cases' and discern the characteristics which are shared in cases that maintain their structure and the characteristics of those that develop in specific ways. For example, by considering all schools that are deemed to be failing they can compare those that address this and those that don't. The state of the system is considered as an emergent property of its previous state, so investigating these states in a range of similar systems allows detection of important causal influences. In a sense then, Byrne & Uprichard do not need Bhaskar's insistence on mechanism. By asserting that complex social systems are real and that there is complex causality, they develop methodological approaches which are aimed at discerning the parameters of systems, which correlate to those systems developing in certain ways.

However, Byrne and his collaborators do have something to say about the autonomy of different levels of reality. Their claims can be compared to what Sawyer (2004, 2005) describes as a 'social mechanistic' approach, which involves considering the interactions of agents on a particular scale, and then seeing how these lead to emergence at some other scale. Sawyer suggests that:

> "Once social properties emerge, they have an ontological status distinct from their realizing mechanisms which may participate in causal relations." (Sawyer, 2004, p. 261)

However, Byrne & Callaghan disagree with Sawyer's formulation:

> "what Sawyer cannot admit is social structure, the existence of collective social entities which persist in some way over and above the actions of individual humans and have a reality beyond them, albeit a time limited reality – the essence of Bhaskar's realist understanding of mechanism." (Byrne & Callaghan, 2014, p. 46)

As we see from the quote above, Sawyer does admit the autonomy of social properties. The subtle difference between the two accounts is that Sawyer insists on structure being emergent from micro-causes. In contrast, Byrne & Callaghan are arguing that even if we allow that social properties have evolved in history and have causal powers today then Sawyer's account is too bound to the 'bottom-up', agent based modelling view of social emergence. Process, relations and conscious agency are important to Byrne & Callaghan beyond the interaction of individual agents. So whilst the accounts of Sawyer and of Byrne & Callaghan agree that real causal power should be attributed at the individual and collective level of social systems, the latter account goes beyond seeing causality as purely involving agent interactions.

In order to reconcile the causal influence of macroscopic social systems (e.g. a classroom) and the agency of individuals, Byrne & Callaghan (2014, Chapter 5) argue that human agency is situated within what Bourdieu calls *fields*. These fields both orientate agency and evolve as people exercise that agency[24]. What is important here is how Byrne & Callaghan use Bourdieu's sociological theory to consider how our views of the world are situated within social fields: how our understandings are *within* social complex systems. Yet they also maintain the capacity of our models to capture something of real causal processes and for us to develop understandings *of* complex systems. In asserting that social entities have complex causal influence, we are forced to better define the status of our models relative to these entities.

2.3.3 Models and Metaphors in Complex Realism

In relating complex realism to Bourdieu's work, Byrne & Callaghan suggest:

> "The status of theory then is that it develops 'models' of systems of relations, which stand, as all models do, as metaphors of reality. It is just this relationship between the epistemology and empirical investigation that makes Bourdieu's work compelling for complexity theory, in which the aim is to achieve scientific laws, expressed as normic statements that can 'give reasoned scientific accounts of reality' (Reed and Harvey 1992: 357)" (Byrne & Callaghan, 2014, p. 110)

Byrne & Callaghan (2014, p. 117) see three key aspects of overlap between Bourdieu's account and this approach to complexity: theory is "discursive with" the system; it is empirically based; it seeks local explanations which recognise the significance of interactions, emergence and agency. As we saw with Byrne & Uprichard's (2012) approach to considering cases rather than

[24] We will further discuss Bourdieu's notions later, and suggest that the position in this thesis provides a more concrete account of human agency (subsection 5.1.3).

variables, the point is that understanding *of* complex social systems is to be achieved by engaging with the particularities of social systems and not by reducing them to variables, agent based models or *a priori* descriptions of the system at hand. This is a powerful insight and allows complexity to be considered 'as it is'.

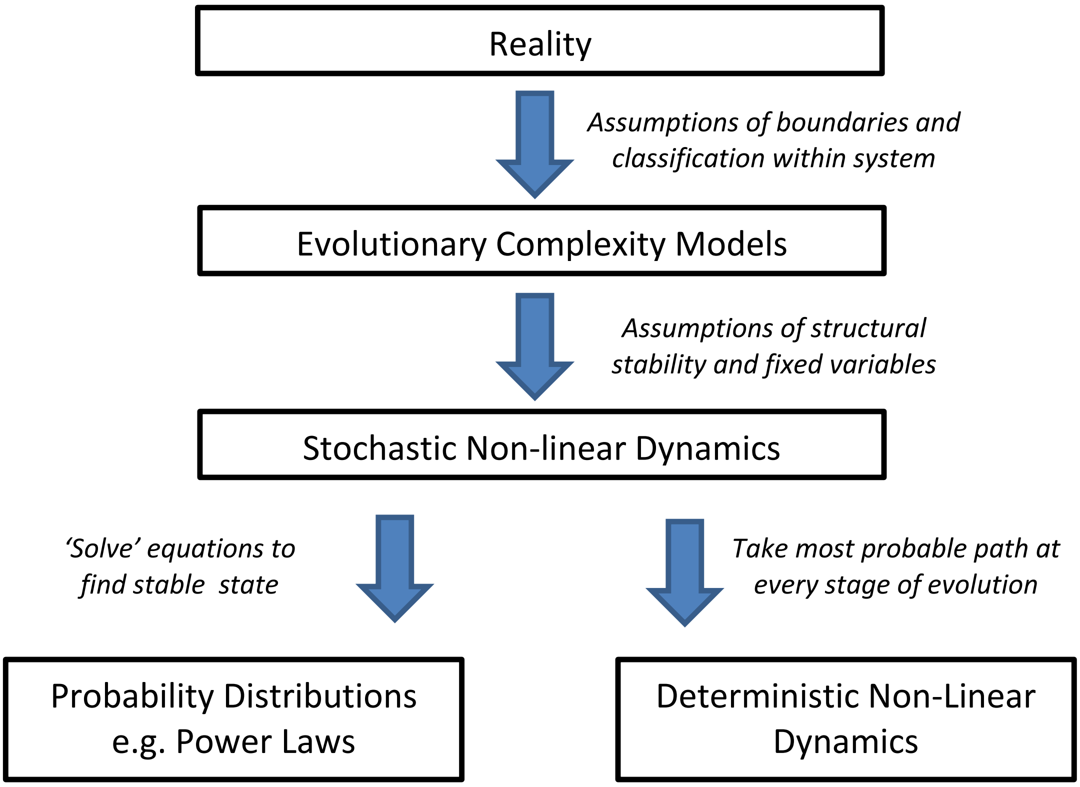
However, there is a tension here in that understanding is seen as bound to the social 'fields' which people inhabit, yet we can have clear representation of the real world. The issue with the complex realist position is that it does not hold up a mirror to itself and recognise that the models that social scientists develop are themselves situated *within* social systems. We will develop this further here by showing that complex realist accounts situate models as somehow 'outside' reality. The reference to models as metaphors in the above quote suggests this, but so too do claims for representation:

> "an ontological take on complexity theory, the complex realism proposed by Reed and Harvey and endorsed by us absolutely requires us to understand the world as being of a particular form, an essentially representational position." (Byrne & Callaghan, 2014: 68)

What is left unresolved is how models of complex social systems relate to the real world: what kind of representation is being argued for? What do Byrne & Callaghan (2014, p. 117) mean by theory being "discursive with" reality? Assuming that complex realists admit that research, policy and practice are themselves complex social systems, we are left with a tension between social understandings being oriented by social 'fields' and the claim for a realist epistemology. Whilst this does not mean that representing the real world is impossible, it does undermine the implication that our descriptions of the social world correspond in a simple way to the world 'as it is'. This is not just a philosophical issue however; it limits our capacity to evaluate why some models of social systems are better than others.

As we saw in subsection 2.3.2, Byrne & Callaghan's (2014, p. 8) form of complex realism includes "the ontological position that much of the world and most of the social world consists of complex systems". However, Allen & Boulton (2011) offer a slightly different form of complex realism in that reality 'just is', and that it is our models which should be labelled as complex. Allen & Boulton are concerned with why some complexity models are better than others. They argue that there is a hierarchy of complexity models relative to how well they represent reality (see Figure 2c).

Figure 2c – Representation of Successive Assumptions in Modelling, adapted from Allen & Boulton (2011)



Without going into detail, their argument is that successive assumptions lead to greater reduction and 'less realistic' models of reality. The distinction between whether reality contains complex systems, or whether it is our models that are complex, can be attributed to whether the term 'complexity' is used in a general sense, or to refer to a scientific discipline. However, Byrne, Callaghan, Allen and Boulton are all claiming that approaches such as case study and modelling are able to represent the social world. What remains problematic is how we are to evaluate models of complex social systems: how some are more realistic than others.

Byrne & Callaghan (2014, p. 6) claim that "Any description of reality is metaphorical" and in subsection 1.3.2 we outlined how this makes any criteria for evaluating models problematic; if models only need be analogy or metaphor then broad interpretation is permissible. In an earlier account, Byrne (1997) discusses computer based simulations:

> "Simulations are interesting and useful because they involve the creation of modelled systems which are analogous in a fundamental way with the social systems which are

our concern as sociologists… There still remains the issue of whether we can model closely enough to achieve the kind of predictive power of the old analogue engineering models, which is the issue of robust chaos, but as analogies simulations have very real possibilities." (Byrne, 1997)

There are a couple of telling points in this quote. Firstly there is the sense of being able to get 'close enough' to reality through models, something which echoes Allen & Boulton's concerns. Both accounts claim that we can develop more realistic models in the sense of models which capture more of the dynamics of the real world. However, we discussed in Chapter 1 the difficulty of this in relation to complex systems. Because the minute detail of a system may be highly significant in the future, any assumption, reduction or abstraction may lead to a model behaving in a very different way to the phenomenon being modelled (see 1.2.1). The point is that all models are deficient because they are not the original system. Without entering into a detailed critique of Allen & Boulton's hierarchy, it is difficult to maintain that any one assumption is more problematic than another. This difficulty in defining what a 'more realistic' model entails may be one of the reasons that Byrne insists on models being metaphor or analogy. The issue is that we must assess the relationship between models and reality on the grounds of whether they are useful to us, rather than through any criteria of them being realistic representations of reality.

> "Models which engage with data do have a connection with reality against which their isomorphism with reality can be assessed." (Byrne & Callaghan, 2014, p. 52)

Whilst a relationship between models and reality is to be upheld, complex realists do not give an adequate account of what this relationship is. Models of complex social systems must be themselves situated within social contexts. This is what leads Cilliers to note that modelling is always an ethical process (subsection 2.2.5).

Asserting the importance of reality in our social models stands complex realism as opposed to purely subjective accounts, or "abstraction without any empirical referent" (Byrne & Callaghan, 2014, p. 40). In defending against such positions, complex realism retreats towards the "rational canons of scientific understanding" (Harvey & Reed, 1996). However, following the work of post-structuralists such a Cilliers there can be no going back. Although we will not expand upon it any further here, the issue is that historically the 'rational canons' of science have seen understandings as somehow outside of the real world: different to the matter they pertain to[25]. Arguably, the insistence of complex realists on 'more realistic' models implies that models are something other than real. This recalls Dewey's argument (see subsection 2.1.5) which reveals that the mind-world scheme offers only subjectivity or objectivity (Biesta, 2011). In arguing against subjectivity, complex realists have sided with objectivity. In so doing they have denied one of the main insights from applying complexity theory to social systems, namely, that our understandings are not objective. Boulton notes that:

> "many complexity modellers of social systems do not really hold such a strict realist ontology about the world; they do not really think the world is entirely objective, real, viewable in the same way by anyone and everyone. To the extent that they would articulate it, they would say that modelling gives useful information, that more subjective aspects of human life are hard to include, and that such 'real' models are a step forwards to gain some understanding of complex situations and point to possible futures and outcomes." (Boulton, 2011, p. 107)

Complex realism attempts to reclaim the importance of investigating real social systems in the world, despite their resistance to analysis. It also recognises the importance of subjective understanding in those systems and the causal influence of social structures beyond individuals. All of this will be upheld in the position developed in this thesis. However, what is lacking in complex realism is an account of how the models we build of classrooms are also context-specific and must be judged relative to modelling as a social practice. Complex realism draws heavily on critical realism, which argues against the epistemic fallacy (see 2.2.4):

> "This consists in the view that statements about being can be reduced to or analysed in terms of statements about knowledge; i.e. that ontological questions can always be transposed into epistemological terms." (Bhaskar, 2008 [1975], p. 26)

However, in analysing critical realism, Bouwel argues that its advocates are guilty of an ontological fallacy:

> "we want to warn for [sic] an *ontological fallacy*: taking an a priori ontological stance which transposes or reduces epistemological and methodological matters into an ontological matter. Analogous to the epistemic fallacy it points at a failure to sustain

[25] This is the case with Plato's 'perfect forms' and Descartes' theory of mind, both of which are dualist positions, as well as with 'self-realising Spirit' in Hegel's dialectic.

adequately the distinction between ontology and epistemology." (Van Bouwel, 2003, p. 85)

Van Bouwel's argument is that by presupposing the reality of mechanism in the social world, Bhaskar focuses methodology upon analysis of those mechanisms. Whilst complex realists do not place such an onus on mechanism, by making an ontological statement about the complexity of the real world they fail to adequately account for the impact on epistemology: they fail to clearly situate our models of the social world within that world.

Post-structuralist accounts recognise the limitations of our understandings within complex social systems; however they are not able to account for how we make sense of the real world (see Section 2.2). Conversely, complex realism makes claims for the complexity of the real world and the importance of relating our models to that real world. However, it does not adequately account for how our models of the real world are mediated by the social systems we inhabit. We will argue in Chapter 3 that a materialist account resolves these issues by recognising that both our understandings and the phenomena they pertain to are real entities which interact.

However, before developing the solution to these issues we must consider one further possibility. If mind and matter cannot be separated in complex social systems, why should we choose matter over mind?

2.4 Social Construction in Complex Systems

2.4.1 Construction in the Real World

We saw above that complex realists do not adequately account for how models relate to the world they seek to model. However, what is clear is that human agency is related to social entities which have real causal power, and that these entities co-evolve with individuals. In this picture, human action is situated as important in the construction of social entities. To repeat a quote from subsection 2.3.2:

> "societies and their institutional activities are constructed by the collective action of human beings, and, thus, are profoundly influenced by the way in which humans subjectively define themselves and their actions. This fundamental difference has already been expressed in Bhaskar's critical naturalist paradigm." (Harvey & Reed, 1996, p. 206)

This view of social institutions as constructed by those within them is implicit in much of the work of complex realists. Maxwell (2012, p. 11) argues that critical realism should be seen as "ontological realism plus epistemological constructivism." In which case, the inheritance from critical realism in complex realist positions extends to an implication that social structures are constructed.

We will here distinguish between social *constructivism* and social *constructionism* by recognising that the former refers to how individual understandings are developed through experience with the world (including social interactions), whereas constructionism refers to the development of social entities by multiple people. In the realist frame, we see that social constructionism is about the development of social entities which have real causal power beyond individuals. However, this implies a distinction between what is individual and what is social, which in turn begs the question as to whether these can be separated.

By advocating the autonomous causal agency of entities such as a school or a social class, complex realists necessarily see these entities as more than the aggregate of individual understandings. As we have seen, complex realists retain a separation of our understandings and what those understandings pertain to, so their account opens up the possibility that mind inhabits a separate ontological category to the real world. Furthermore, we have seen that Cilliers' form of post-structuralism falls short of explaining how the real world and our understanding of it are related (subsection 2.2.6). Therefore, both complex realist and post-structuralist accounts of complex social systems allow mind to be considered as ontologically distinct from the material world. We thus need to evaluate whether social construction can explain the relationship between individuals and social entities within complex systems.

This is not just important from a theoretical perspective however; it also brings us firmly into the realm of learning theories, which are of direct relevance to this thesis. Commonly cited models of learning, such as those of Piaget (1929), Bruner (1966, 1978, 1983), and Vygotsky (1978) are denoted as constructivism within contemporary educational literature. Whilst these do not present a single view of learning (Shayer, 2003), a discussion of social constructionism here will allow us to engage with these dominant discourses in Chapter 7.

We will show that social construction provides an account of how we come to have shared understandings of the world, and highlights the importance of social interactions in this. However, we will also see that it is impossible to maintain that either individual minds or social entities inhabit a separate ontological category to the material world. In order to mount this critique we shall consider Stacey's theory of learning as involving "complex responsive processes" (Stacey, 2001, 2003a, 2003b, 2005). Stacey attempts to define learning within complexity theory and his position is therefore suitable in highlighting the difficulties of considering social construction within complex social systems.

2.4.2 Complex Responsive Processes

Stacey (2001, 2003a, 2003b, 2005) develops the model of complex responsive processes to describe how the interaction of individuals simultaneously results in their learning but also the "patterning" of social communication. There are essentially three ingredients to this: Elias's account of power relations, Mead's symbolic interactionism, and complexity models:

> "The theory of complex responsive processes draws together Elias' process sociology and Mead's symbolic interactionism as ways of translating analogies from the complexity sciences into a theory of human action." (Stacey, 2003a, p. 17)

For Mead (1934), when one animal gestures to another they "call forth" in that other a response and this constitutes a social act. Humans are aware of the possible responses in others and this allows them to recognise what Mead called 'significant symbols' such as shouting, because it allows the person shouting to embody the fear or anger in the person being shouted at. Furthermore, because humans use a sophisticated language system, they can predict a range of responses to actions. Stacey thus defines mind as the "silent role-play" that humans enter into when anticipating each other's responses.

> "The private, silent conversation of a body with itself is the same process as public, vocal conversation between bodies and in this sense mind is always a social process even though it is the individual conducting the private silent conversation." (Stacey, 2001, p. 227)

He draws on Mead's distinction between the "I" which is individual and the "me" which is the embodiment of a *generalised other* which allows this self-conversing. We might therefore see the "me" and the generalised other as constituting the social sphere.

To explain how this distinction of "I" and "me" develops in children, Stacey (2003a, p. 98) talks of how they understand, through play, that they can hide things from others. The child develops a capacity to "be alone with others", that is, to imagine how others might respond and to be self-aware. Furthermore, Stacey argues that this is an important part of development as it allows a child to demark his/her inner world and that which is outer: the distinction between "I" and "me". An example of Stacey's thinking is revealed in his account of how a child may become attached to a comforter or blanket:

> "In Mead's sense, however, the blanket is not a symbol at all because it is not a gesture made by the child calling forth a response in another or in himself. The symbol is the child's gesture to the object and the imagined response of that gesture." (Stacey, 2003a, pp. 97-98)

Such a blanket becomes part of the silent role-play that a child undertakes in learning how to invoke a generalised other and this is part of the development of that other. Therefore we are to understand the generalised other to be what allows self-awareness.

Mead's work is widely credited with being the inspiration for symbolic interactionism (Hier, 2005) which has fallen into and out of favour over the last 50 years (Fine, 1993). Whilst the critique below may also be levelled at symbolic interactionism therefore, we shall here confine analysis to how Mead's notions are used by Stacey in developing his account of complex responsive processes.

In addition to Mead's work, the work of Elias (2000 [1939]) is important to Stacey because it recognises that although social reality is constructed through interactions, power relations emerge which account for social structures; as global patterns of society become more complex so too do individual lives (Stacey, 2005, pp. 41-44). Elias's work thus recognises that there are socialising influences which have evolved and which provide "stresses" and the need for self-control. The strength of combining Mead's responsive processes with Elias's notions of power relations is, according to Stacey, that it allows us to understand how the individual influences the social, whilst themselves being socialised.

If we are to conceive of the individual and social as the same thing, what is missing is an account of how patterns are imparted and develop over time. Stacey believes that complexity science paves the way forward on this by providing a causality in which fluctuations lead to systemic change.

> "Learning is the activity of interdependent people and can only be understood in terms of self-organizing communicative interaction and power relating in which identities are potentially transformed." (Stacey, 2003b, p. 331)

Stacey draws on the work of Prigogine and biological models (such as those of Kauffman and Allen) from the turn of the century, which show that semi-stable states may emerge from fluctuations. He sees this as "analogous" to how meaning in social situations is also prone to dynamic emergence.

In considering the relevance for teachers, Stanley (2009) characterises complex responsive processes as a learning theory, and the implication is that understanding a classroom as the site of shared gestures would influence the way teachers behave:

> "As a social act, the "gesture-and-response" structure of interaction between students or teachers-and-students constitutes meaning for all involved (in some way and even for other listeners) as every gesture by one person calls forth a gesture by another. The co-emergent meaning lies in the relational nature of the classroom every affect prompts an effect and so on. Where meaning does not rest within any "part" of the gesture-and-response structure, i.e., "within" the individual, meaning does arise as a result of interaction (that begets further interaction)" (Stanley, 2009, p. 37)

We thus see that complex responsive processes as a theory of learning suggests a co-construction of meaning and resists meaning being situated in specific parts of the system, in echo of our earlier discussions around distributed representation and its importance in Cilliers' work (subsection 2.2.4). Learning is not something which happens in individual minds but which emerges through interaction. In this way, Stanley suggests, the rich histories of classrooms provide "values, beliefs, traditions, habits, routines and procedures" (Stacey 2003a, p. 65), which change slowly over time but which provide coherent patterns of thought.

The strength of an account such as Stanley's is that it focuses teachers and researchers on the interactions within classrooms and gives an understanding of shared meaning and historic context. It also provides ways of reconceptualising aspects of practice. For example, Stanley considers the role of the teachers in preparing lessons as one of self-reflexivity in which they bring forth in themselves the possible responses of pupils. On the surface therefore, complex responsive processes are able to account for shared understanding within classrooms and also the emergence of new understandings over time.

However, we will now turn to the issues with such a social constructionist account of learning. Firstly, we will see that in order for meaning to change over time there must be some appeal to interactions in and with the real world. As with the account of complex realism, we will see that if you have both a real world and minds interacting with it, then any attempt to separate them must fail. Secondly, we will see that equating the individual and social is untenable, as it relies on the Hegelian notion of 'paradox'.

2.4.3 The Generalised Other and Hegelian Paradox

Complex responsive processes refer to the development of the individual and social as the same system, through the gesture-response of interacting people. Stacey also refers to the importance of history in the co-construction of meaning and the evolution of social norms. However, it is far from clear whether the components of this argument fit together. Most notably, there is a tension between Stacey's interpretation of gesture-response in Mead, and the social evolution attributed to Elias (both most fully developed in Stacey (2003a)). In order to allow the kind of social evolution that Elias discusses we must have a generalised other that is both shared and undergoing change, but it is not clear how this can be the case.

Stacey (2001) argues against seeing the social as some supra-individual system and as such we must conclude that when an interaction changes the meaning of a shared notion, this meaning is not changed for everybody in society. Thus there must also be a dynamic aspect to complex responsive processes: the generalised other must vary over time and space. There must be geographical variation in understanding and indeed it seems that the generalised other must be different for everybody, as it is context-specific. Conceived of in this way, mind can still be seen as social in that we are able to predict the actions of others. However, when you make the generalised other dynamic by allowing that different people at different times have different understandings, you have to accept the influence of the real, temporal and spatial world. You also undermine the notion that the social is shared.

The generalised other in Mead's work provides an account of how we come to share understandings and is linked by Stacey to the adherence to social norms that Elias talks of. However, given that people experience different interactions in their lives, and that young people learn how to deploy this generalised other over time, it is untenable that there is a single generalised other that we all share. We must accept that this other is different for different individuals and this somewhat weakens Stacey's claims that minds constitute the social sphere. The social becomes the aggregate of individual minds, and this does not allow causal agency of social entities beyond the specific interactions of minds.

Stacey (2003b, 2005) seems to be aware of the difficulty of equating the individual with the social. However he attempts to resolve it by drawing on the untenable notion of 'paradox' which he claims comes from Hegel and which in turn influenced American pragmatists including Mead and Elias:

> "what is required is a different logic, such as the dialectical logic of Hegel. In this kind of logic, the word paradox means the presence together at the same time of contradictory, essentially conflicting ideas, none of which can be eliminated or resolved. Indeed it is this conflict that gives rise to the transformation that is central to Hegels' dialectical logic." (Stacey, 2003b, p. 5)

However, Stacey distances his model of complex responsive processes from Hegel's metaphysics in claiming that both Mead and Elias adopted the Hegelian notion of "self-realisation" but in terms of human consciousness, not absolute Spirit (Stacey, 2003a, p. 214). This "self-realisation" is evident in the separation of the "I" and the "me" in Mead's account and we have already seen that separating what is individual from what is social is difficult, to say the least. By relating to Hegel's logic we are being asked to see the "I", which allows conscious decision as somehow privileged over the "me", which is social. This separation is intended to account for aspects of human behaviour such as deception, whereby there is conscious or 'sub-conscious' decision on the part of an individual to manipulate the anticipated response of another. However, in an account of how the individual and the social are the same thing we are being asked to accept that the "I", the "me" and the social are all aspects of the same entity: a trinity of the self/mind/social. Educationalists are to accept that "learning occurs as shifts in meaning and it is simultaneously individual and social" (Stacey, 2003b, p. 8).

Even if we were able to adopt such a logic, and there is no motivation for doing so, two significant problems remain. Firstly, by recognising that mind is different to different people, we still reduce the social to the aggregate of individual minds. Secondly, there is no account of the role the real world plays in developing understandings.

In considering the first problem, we see that different people have different experiences which will condition their responses and the responses they anticipate from others. Beyond this though we also expect different responses in different spheres of our lives: from family, colleagues, and friends. Furthermore, we know how people close to us might respond in particular ways: a very specific 'other' rather than a generalised one. There must be some sense in which mind is individual therefore, even if we accept that mind is the predicting the response of others. This breaks down the separation of "I" and "me" in Mead's work, because they must both be individual and context-specific.

The generalised other and the "me" are quickly reducible to a recognition that humans can empathise with each other. This is an important aspect of social learning, but it is not sufficient to define social entities such as classrooms. The issue at hand is that we cannot account for the causal powers of social entities through empathy alone. Whilst empathy allows us to anticipate the responses of others (following Mead), and our capacity to use this to deceive, manipulate and coerce explains aspects of human behaviour (the power relations that Elias discusses), it does not allow for the causal power of social entities. For example, applying Stacey's account to a classroom (as Stanley does) suggests that for the teacher, the social is made up of the anticipated responses of their class. Experienced teachers will anticipate different responses in different pupils, rather than any "generalised" response. At best we can argue that teachers plan for an 'average' pupil within the class but this is not the same as a specific class of pupils having a causal influence on the teacher's planning.

If we look on a larger scale the problem becomes more pronounced. Rather than afford something such as 'school ethos' with a real causal influence upon an individual pupil, we must accept that pupils are actually influenced by the specifics of their relationships with people in the school. Social construction accounts for how people interact through anticipating each other's responses, but it reduces the social world to the aggregate of such social interaction. Rather than having a direct influence on individuals therefore, the influence of macroscopic social entities is manifest through myriad individual interactions. In recognising that the generalised other is actually a host of specific others, we see that individuals must be constantly anticipating the responses of many others in real time[26]. It seems unlikely that people are constantly calculating the responses of everyone in a classroom.

We will develop an alternative explanation in this thesis: that human brains are able to respond to patterns of behaviour in others without the need for a dialectic generalised other. What is important here though is the conclusion that complex realism is not compatible with social construction: the latter cannot provide social entities with autonomous causal powers. Complex realism advocates the (complex) causal power of social entities, but on its own does not give an account of how social entities arise and how they influence individuals. Conversely, social construction cannot afford causal powers to anything beyond individual interactions and the empathy involved in these.

We have already seen that social construction, after Stacey, has a number of issues. Firstly it does not adequately support the separation of individual agency and the shared understandings of people within complex social systems. Secondly, it draws on an untenable 'Hegelian logic' to try and equate the social world with empathy in individuals. Social construction does not fit with either an account of dynamic social complexity, or with ontological realism. However, this mismatch between realism and social understandings highlights a further issue, namely, that social construction does not adequately account for the role of the real world in the development of our understandings. This is worthwhile considering further as it highlights the difficulties of social construction as an account of how we develop understandings: how we learn.

2.4.4 The Real World as Socialising

Because Stacey focuses on how understanding comes about through social interaction, he does not give a clear account of the role of the real world in developing such understandings. Stacey does not appear to be denying a world external to humans (as extreme forms of social construction might). This is evident from his reference to complex responsive processes being related to the evolution of the body (Stacey, 2003a, p. 242) and also in passing references such as to a child's blanket as discussed above or to "artefacts used by members of organisations in their work together" (Stacey, 2003b, p. 2). However, he clearly separates the social mind from the body:

> "The theory of complex responsive processes holds that mind is not inside a person, does not contain representations, does not involve the retrieval of memories from a

[26] This echoes post-structuralist accounts in which meaning is constantly deferred (see subsection 2.2.5).

> store somewhere and is not genetically programmed or determined by instincts." (Stacey, 2003a, p. 101)

Mind is being characterised as beyond the material of brains but it is not clear how this is the case. By showing that mind, as the imagined response of others, is different to different people, we are forced to accept social understanding must differ across time and space. This is self-evident when we consider that human understanding has been different throughout history and differs throughout the world. In this sense then, social understanding is linked to spatial and temporal aspects of the material world.

Beyond this though, even constructivist theories of learning, which might be seen as linked to the social constructionist position, account for learning from the real world. For example, both Bruner (1983) and Vygotsky (1978) discuss the role of other people in supporting learning so at the very least we must account for the happenstance of these interactions in time and space. Furthermore, take Piaget's (1929) account of how children learn from assimilating new experiences: the child actively constructs their understanding of the world through play and experimentation.

Consider the example of a ball, which could be said to be part of a role-play that children undertake in playing the game of football. This has many social aspects in terms of the rules and status of the game, in terms of relationships to teammates and opposition and in terms of the goal of deceiving and outplaying the opposing team. However, in learning how to kick a ball the child is experiencing not just a social role-play but is also learning about how a ball responds when kicked, about how muscles are used to produce such a kick and about the influence of wind and rain on the ball. People learn through interacting with the world outside of social interaction.

Even within the social world though, it is not easy to define what is social within learning. For example, how are we to interpret the capacity of children to learn by watching the actions of others (Bandura, Rusec & Menlove, 1966)? This might be construed as invoking a generalised other, but in the case of watching the television we cannot see it as a social interaction in the sense of co-constructing meaning. Images, audio and written text must be seen as a stimulus for a 'silent role-play with oneself', not to mention art forms and ancient artefacts. These media certainly have a social aspect to them in terms of a shared symbolic language but this stretches to breaking point the notion of a generalised other.

The issue is not in what we should define as social or otherwise however, it is in the claim that we must distinguish between learning through social interactions and through learning in the real world. It takes a separation of mind as social and brain/body as individual to maintain this. We will show in this thesis that seeing the social world as part of the material world is the way to resolve this without the ontological difficulties seen in Stacey's position.

Humans have at least the capacity that all primates do to learn about our environment and solve new problems. Therefore the real world must have a role in shaping us as individuals because we have different experiences to each other, social or otherwise. Yet, we share symbolic language and have shared understandings of the world and this must also come from social interactions over time. This is the difficulty that social constructionists like Stacey seem to be trying to get at: that we have shared understanding yet are individuals. What they omit however is the role of the objects and symbols (in the sense of letters, sounds, numbers etc.) that we interact with in socialising us. This is particularly true when we consider the education of young people, who are being socialised in the norms and understandings of the world they are born into, through their experiences.

Social constructionism attempts to separate our social learning from the material world. Whether we place a special emphasis on human agency, or on empathy, or on social structures, or on symbolic language, it is impossible to escape the fact that these are all part of the same system and are all part of the material world. It is folly to try and distinguish between what is socially constructed and what is a consequence of our interactions with the real world. In doing so we quickly lose the ability to distinguish and become lost in attempts to separate mind and matter. We also imply an anthropocentric view that we are somehow different from the material world, and that our understandings and social structures are somehow supernatural.

If we accept that we are part of a material world, and we must, then we must also accept that our understandings and social structures are part of that real world. We cannot support a view that the construction of human understandings is anything other than the interaction of matter.

2.5 Chapter Conclusion – Situating Human Understanding

In this chapter we have critically evaluated four strands of the contemporary complexity literature: complexity science, post-structuralist complexity, complex realism and social construction. As outlined in the introduction to the chapter, the range of concerns and approaches, as well as the differing positions in relation to ontology and epistemology, mean that complexity theory is a broad church, even when restricted to considering social systems. By way of concluding this chapter we will consider the issues that each of the four existing positions face, and how these inform the position which is developed across Chapters 3, 4 and 5.

In relation to both Richardson & Cilliers' (2001) category of "reductionist" complexity science, and Morin's (2007) claim that much of complexity science is "restricted", we saw in Section 2.1 that complexity science adopts methods and assumptions that do not fully recognise the difficulty of representing a complex system. However, this is not necessarily because scientists are blind to the issues that nonlinear, dynamic social systems present. Instead we should see complexity science as itself a complex field (Castellani & Hafferty, 2009). The motivations for developing models include the honing of techniques and developing models which are 'internally consistent' with existing accounts, rather than just seeking to provide accurate accounts of the social world. The variety of approaches and motivations within complexity science means that there is no coherent account of how we are to consider human understanding within social systems, nor a clear account of the epistemological assumptions used in developing models of such systems.

Agent based models, power law models and network models have different ontological and epistemological foundations from each other, although all adhere to our definition of complexity science (see 2.1.5). Agent based models characterise understanding as the processing of algorithms by brains, implying interaction with the modelled environment. As far as the epistemology of these positions is expressed, models are attempting to 'backwards engineer' causes from the social phenomena being explored. Power laws describe statistical relationships and as such are not concerned with the specifics of human understanding at all. Such models are couched in language which implies the uncovering of laws, although in reality power laws are context-specific statistical relationships. Network models however have a different set of ontological assumptions in that they require that relations between people have causal power, whilst not presently being able to explain the role of individual agency within these networks of relations.

What is required is a theoretical position which is able to account for such a variety of models and modelling approaches. We have already achieved elements of this. By proposing that complexity science as a field should be seen as a complex system, we situate the models and practices as being motivated by social concerns, as much as a quest to describe the world as it is. Rather than epistemological claims that models represent reality or that laws are being uncovered, we see that models must be positioned within the social realm. However, this needs further development in order to relate models to the world that they seek to model, and allow critique of models which do not have empirical correlates. This is not to say that models deployed to teach students or to develop techniques have no place, it is instead to seek clarity in how models of social systems, such as classrooms, are to be related to those systems.

We saw in subsection 2.1.5 that complexity scientists appeal to pragmatism to escape discussion of ontological and epistemological concerns in favour of what is 'practical'. However, closer inspection of pragmatism, particularly Dewey's account (Biesta, 2011; Olssen, 2011) reveals that it is concerned with arguing against the separation of objectivity and subjectivity, and in this sense might be seen to anticipate the work of post-structuralist complexity thinkers (Section 2.1). Davis & Sumara and Cilliers provide accounts of how we cannot sustain the distinction between our understandings and the world which they pertain to. However, we saw that we cannot justify the links between post-structuralism and complexity on the basis of 'analogy' alone, as this undermines any attempt to evaluate descriptions and allows potentially harmful notions such as attempting to "promote emergence" (subsection 2.2.2). This, once again, highlights the need for a clear positioning of our understandings relative to the social and natural world.

Cilliers' more careful linking of complexity and Derrida's deconstruction (subsection 2.2.3) showed that meaning cannot be characterised as the direct correspondence between the world as it is and our accounts of it. Meaning instead is determined in différance to the system of symbolic language that we use to make sense of the world. Such an account recognises that understandings are partial. However, because of the reliance upon Derrida's form of literary critique, Cilliers' account describes a system in which meaning is constantly deferred and it is impossible to make affirmative statements about the world. We saw in subsection 2.2.5 that Cilliers attempts to overcome this by appeal to the boundaries of understanding and our statements within those boundaries. However we are still left with the intangibility of these boundaries.

There is another issue with Cilliers drawing on Derrida though. Because Derrida considers systems of meaning and language, whereas Cilliers draws on artificial neural networks, brains and social systems, Cilliers does not make clear the differences between these systems, or properly define what he considers to be within the real world. For example, how do brains, social systems and systems of meaning interact? We have proposed that the difficulties that Cilliers' account faces, both in terms of being unclear about how systems relate to each other, and the need to constantly consider what is outside boundaries of understanding, are inherited from Derrida's form of deconstruction. As we argued in subsection 2.2.6, Derrida's account is unable to fully escape Hegel's untenable dialectic positon. Therefore whilst Cilliers' account provides a clear synergy between post-structuralism and complexity, and describes how our understandings are partial and tentative, these features must be uncoupled from such metaphysics. What is required is an account of partial understandings and distributed representation without the need for constant deferral of meaning. We must better situate our understandings relative to the real world.

In contrast to both complexity science and post-structuralist approaches, complex realism is clear in the importance of the real world. It asserts the reality of social entities which have causal power, for example the influence of a classroom on those within it. This clear ontological positioning allows the development of methodologies which seek to explore the complexity of the world as it is and thus reinstate the importance of empirical evidence. This is to be upheld in the complex materialist position.

Complex realism has its foundations in Bhaskar's (2008 [1975]) critical realism, although the importance of mechanism is downplayed in favour of methodologies which compare cases in which change occurs to those in which it doesn't (Byrne & Uprichard, 2012). Such approaches recognise the nonlinear, dynamic and sensitive nature of complex social systems and in this sense overcome Morin's (2007) definition of "restricted complexity", save for in one regard. By making the ontological argument primary, complex realists do not fully develop an account of epistemology: they do not position their models as also being part of social systems. In reinstating social science's concern for investigating real systems, complex realism returns to the implication that our models correspond to reality in a simple way. Despite Byrne & Callaghan (2014) drawing upon Bourdieu's notion of human agency as being conditioned by the 'social fields' people inhabit, there is no recognition that as social scientists our models must also be conditioned in this way. This tension is manifest in Allen & Boulton's (2011) attempts to describe how some models are 'more realistic' than others, implying a capacity for models to approach reality. This is the very position that post-structuralist accounts manage to undermine.

The theoretical position developed in this thesis will assert the importance of the real world and seek to link models and descriptions to it, as well as uphold the methodologies that Byrne & Uprichard (2012) develop to explore social systems. However, what is required is a way to reconcile a realist ontology with the insight that our models and descriptions are socially situated. We cannot return to an epistemology which assumes that our models describe the world as it is, without the mediation of the linguistic and symbolic systems we deploy.

Whilst complex realists do not provide a sufficient account of how we come to develop understandings in the world, their drawing on critical realism suggests a link to social constructionism (Maxwell, 2012). Social construction provides a process by which people come to have shared understandings, by invoking a generalised other (after Mead, 1934). Stacey (2001, 2003a, 2003b, 2005) develops the model of complex responsive processes which brings together this generalised other with recognition of the power relations which exist in the world and the development of complex social systems.

However, in developing this form of social construction a tension arises between the capacity of people to call forth this generalised other and the realisation that in a dynamic system the responses people expect from each other will be context-dependent. Whilst Stacey situates mind as outside of individual bodies therefore, this leads to the social world being the aggregate of the anticipated responses of people. This shares with Cilliers' account a need to constantly process meaning within a system in real time, but also shares reliance upon Hegel's metaphysics. Whilst the importance of empathy in shared understanding is to be upheld, this cannot be based on a 'logic' of the social being simultaneously personal and shared.

Social construction, as developed by Stacey, is not able to attribute social entities with causal influence beyond the aggregate of individual interactions. It also focuses too heavily on the role of social interactions and in so doing neglects the role of the real world in developing our understandings. The temporal and spatial influence of how we come into contact with others will determine how our understandings develop over time and in this sense the real world influences us. Additionally however, we learn by engaging with the world beyond social interaction. Even if our interpretation of these experiences is influenced by our prior social experience, they cannot be said to be purely social interactions. We need a position which is able to not only situate our understandings relative to the real world, but also describe how they are influenced by that world.

In bringing the various threads of this chapter together it becomes apparent that a theoretical position capable of underpinning social complexity must do three things: it must be able to account for the role that the real world plays in developing our understandings; it must situate our understandings relative to this real world; it must account for how our models and understandings are themselves within complex social systems. Over the next three chapters we will develop a theoretical position capable of fulfilling these three criteria. This will allow us to see how real, social systems and our understandings within them can be described using complexity theory. In Chapter 8, we will then be able to show how the position developed overcomes the issues faced by the existing accounts of social complexity which have been discussed in this chapter.

3 Complex Materialism

3.0 Chapter Introduction

We concluded our review of existing literature with criteria for a theoretical position capable of situating learning within a complex social system such as a classroom. Over Chapters 3, 4 and 5 we will develop the position of *complex materialism* to meet these criteria, before discussing its implications in Chapters 6 and 7.

At first approximation, complex materialism contains two aspects. Firstly, it asserts that everything in the world has a material basis. This includes the heterogeneous elements of a classroom: objects, text, music, images, speech, even thoughts. This may initially seem like a more extreme view than that held by complex realists therefore (section 2.2), because it stresses the fundamental role of the material which constitutes the world. Indeed, the use of the term *materialism* is intended to distinguish between the position developed here and complex realism. However, the word *complex*, reminds us that the material world is not reducible. Emergent structure and patterns cannot be traced back to the exact context of their formation, nor reduced to their material components. This begs the question as to how they can have influence, and how it is that we recognise and respond to macroscopic patterns in the world.

This brings us to the second aspect of complex materialism, namely a description of how our brains are able to respond to, replicate and manipulate patterns. We will show that there is a relation between the neural patterns within our brains and the spatial and temporal patterns which exist across all scales of the material world. Again, this is not to imply the possibility of reduction; brains do not have a simple representation of the world 'as it is'. However, by seeing brains as part of the material world we can account for how our understandings adapt to the world around us, and in turn how this shapes our influence on the world. Combined with a materialist position, understanding brains as adaptive allows us to assert the influence of patterns across all temporal and spatial scales and include the heterogeneous aspects of a classroom. We will thus describe how pupils learn within classrooms and highlight the context-specific and nonlinear nature of this learning. However, we will also recognise the unique and irreducible way in which learning takes place and thus the limitations of any theoretical account of learning.

These ideas need considerable clarification, and to that end Section 3.1 will provide a first sketch of complex materialism and how it answers the requirements developed in Chapter 2:

explaining the role the real world plays in learning; situating our understandings relative to this real world; accounting for how our models are themselves within complex social systems. This first sketch is intended to orientate the reader rather than fully elucidate the position being proposed. Following this initial orientation, Section 3.2 will outline the materialist position being adopted. Chapter 4 will then draw on contemporary understanding of brain function to show how learning should be considered a material process. Whilst this will provide an account of how individuals learn, Chapter 5 will expand on this to describe how people come to have shared understandings. Thus, complex materialism will be developed over the next three chapters. We shall turn to the implications for researching classrooms in Chapter 6, and the implications for how we view classroom learning in Chapter 7.

3.1 A First Sketch of Complex Materialism

3.1.1 Social Complexity in the Material World

Complex materialism can be seen as the combination of an ontological position which asserts that everything in the world has a material basis, and an epistemological position which recognises that our brains form distributed representations of the world around us. We will here consider the materialist position, before developing it further in Section 3.2.

The ontological stance of this thesis is inspired by Deleuze's (2004a [1968], 2004b [1969]) monist position which asserts the reality of all aspects of the world: objects, our thoughts, our emotions, our social relations, music, art etc. These are all fundamentally constituted by a single 'material'. Deleuze worked within the tradition of continental philosophy and as such in 'translating' his ideas into the analytic tradition and relating to complexity theory we will provide concrete accounts of the processes involved, and undoubtedly interpret Deleuze's work in a way which would be unpalatable to scholars of it. Nevertheless, we are aiming at a theoretical position equal to learning in complex social systems, rather than the advancement of philosophy itself.

To begin this 'translation' in earnest, we will suggest that whilst Deleuze sees the world as constituted by "pure difference" (Deleuze, 2004a [1968]), his account is commensurate with contemporary scientific views, such as that of string theory. String theory proposes that all energy and matter can be accounted for by the existence of one-dimensional strings at the subatomic level. The specific details of string theory are of secondary importance to the point that the notion of 'pure difference' can be replaced by contemporary understandings of matter[27]. What complex materialism takes from Deleuze is a 'flat ontology' in which mind, matter, and all aspects of the natural and social world are considered to be within the same ontological category.

Adopting a monist position is important to classrooms because it allows that the heterogeneous elements of a complex social system can influence our understandings, be they music or ideas or text books. In so doing it allows us to escape the separation of mind and matter which haunts existing accounts of social complexity. Post-structuralist accounts (Section 2.2) are not able to resolve what is real and what is not; complex realists (2.3) situate their models outside of the social systems they explore; social construction (2.4) is unable to

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[27] Physicists are currently trying to link gravity, as described in general relativity, with quantum theory to provide a 'theory of everything', and string theory is a candidate for such a theory. However, the arguments within this thesis would be sustained should physicists come up with a different account of the 'material' which constitutes the universe.

sustain the social mind and individual thought, or account for matter. The separation of mind and matter in a complex system is difficult because they must be seen to be interacting in nonlinear and dynamic ways. If we accept that people learn through interaction with the real world then it becomes problematic to describe where the material world ends and a world of ideas begins, as well as how they influence each other. Recognising that our minds are constituted by the material of our brains/bodies resolves these issues, and we will explore this further in Section 3.2.

The assertion that the universe consists of a single material may at first seem unpalatable, as we understand that there are different objects in the world, but also that we have ideas and dreams which do not appear to have a material reality at all. As Harman questions:

> "if the underworld is truly unformatted, then it is hard to see why it should suddenly be broken into parts by a human, who really ought to be just sleekly fused into the unformatted plasma as everything else." (Harman, 2011, p. 61)

In response to this we see that monism, the world being made of a single material, does not necessitate it being "unformatted plasma". Contemporary scientific understanding is that after the big bang there were tiny differences in the distribution of material across the universe which, over cosmic timescales, resulted in the world as we see it today. Only the presence of subatomic particles and gravity in space and time is needed to account for the complexity of the world, and furthermore approaches such as string theory hope to provide a singular account of this.

However, Harman's questioning of how the world is "broken into parts by a human" is not so easily answered, and indeed the history of philosophy contains many proposals for why this is the case[28]. Deleuze's (2004a [1968]) solution is that when we encounter similar experiences within the world, we associate them with a concept. So thought is seen as a material response to experience in the material world. Whilst taking this as the starting point, we will develop such a proposal with appeal to both Cilliers' model of distributed representation in the brain (touched upon already in subsection 2.2.3) and the support for this model within contemporary neuroscience. Chapter 4 will thus detail how the combination of Deleuze's metaphysics and models of distributed representation within the brain allow us to describe

[28] For example, Plato postulated a supernatural world of ideal forms which exist beyond the material world. Kant instead proposed that reason is structured with categories, such as cause and effect, which condition our experience. Deleuze (2004a [1968]) stands against both of these in disallowing ideas or reason to pre-exist experience.

how humans come to understand the world within complex social systems. As intimated above, drawing on Deleuze overcomes the separation of mind and matter which troubles the existing accounts of social complexity. However, combining this with a model of brain function translates Deleuze's metaphysical account into a physical one and provides clear mechanisms for how this happens.

3.1.2 Situating Understandings

In a first sketch of how human understanding comes about therefore we will here propose that our experiences result in electrical patterns in the brain which condition our response to the world. Cilliers' (1998) account of distributed representation allows us to explain how human brains respond to and understand the world without treating knowledge as anything other than a response of the brain to experience. So our experiences influence brain structure in a complex way and this explains how we respond to the world whilst being part of it. In a crude way therefore we might say that learning is related to the adaptation of our brains to the world we experience. However, we must recognise that our biology and evolutionary history play a role in determining how our brains develop and respond, as well as our experiences.

This does not paint a complete picture, because it does not account for how we come to have shared understandings, or utilise a shared symbolic language. By 'shared understandings' we here mean the capacity of humans to respond in similar ways and to empathise with each other. This thesis will go as far as proposing that these shared understandings come about through interaction with each other and with *patterns* within the social world. In Chapter 5 we will define these patterns more clearly, here however we will assert that these patterns have a material basis. Learning from each other includes empathy, imitation and coordination through our shared biology[29]. Learning from the material world involves us being able to respond to associations between heterogeneous aspects of the material world: words, images, behaviours and context. So, for example, the word 'football' becomes associated with the rules of a game but also a set of associated behaviours. In this way our understandings adapt to the experience of events in the real world. However this is not a one way street, our understandings and actions result in the manipulation of the material world, including the symbols and media within the human realm. In this sense therefore, the theoretical position developed in this thesis is not inert in relation to theories of learning, and we will see in Chapter 7 how it allows critique of existing notions of learning within classrooms.

[29] Mirror-systems within the brain are likely involved in social interaction (Tognoli et al., 2007; van Baaren et. al, 2009), suggesting an evolutionary basis for shared understanding. See Section 5.2

In developing a materialist position, we see that classrooms are what Deleuze (2007) calls a "hodgepodge" of brains, objects and symbols. Shared meaning is emergent from these hodgepodges but we need not see it as anything other than material in nature. To elucidate this consider the dying out of a language, which has undoubtedly happened many times in human history. If everyone speaking the language dies, and no symbolic representation of the language remains, then the language: the words, modes of expression and patterns of association die out also. A system of meaning such as a language is thus constituted by the electrical activity of the brains which sustain it and the symbols and media within the material world which encode it. We do not need a language to die out to see that systems of meaning, be they linguistic, mathematical or artistic, develop over time and that this development relates to interactions within the material world.

However, this does not mean that we can reduce a system of meaning to its material basis. As was outlined in Section 1.2, complex systems cannot be reduced for a variety of reasons: firstly, nonlinear causality means that we cannot discern clear causal links between parts of the system. Secondly, the importance of the history in complex systems means that small details may (or may not) come to determine their future trajectory. Thirdly, complex systems are open to the environment, so cannot be isolated for the purpose of description[30]. Fourthly, we have no way of reducing or explaining brain patterns, so if we accept that they constitute part of the social world there is further difficulty in reduction. These reasons mean that in practice, we could never reduce a complex social system. However, notions such as quantum indeterminacy suggest it may not be possible in principle either (see subsection 1.2.2 for a full account of this). We thus see that under complex materialism, the social world is material but not reducible.

If we cannot reduce complex social systems to the material that constitutes them, then how might we maintain the causal influence of macroscopic social entities[31]: how does a classroom influence a pupil? In answer to this we will explain how humans develop responses to patterns within the world, but how this is not confined to any specific scale of analysis. In Chapter 4 we will outline Cilliers' model of how brains do this and then consider the contemporary support for such a model. We will suffice to say here that the brain is capable of delineating macroscopic social entities, as well as specific people, or objects within them. This is due to

[30] For example, new words are added to the English language each year, corresponding to new understandings in the social world but also new 'discoveries' in the natural world. A language as a complex system must thus be considered as open to these environments.

[31] This is a primary concern for complex realists such as Byrne & Uprichard (2012) and Sawyer (2004). See subsection 2.2.3

distributed representation, which we discussed in subsection 2.2.3. A pupil does not need to have a detailed representation of a classroom, or even notice much of the detail, to form a response to it. In this way macroscopic entities such as 'school ethos' or 'being working class' may leave an impression on a person and might have an impact. That impact though will be conditioned by their previous experiences (which will determine the configurations already in their brain) and the experiences they have in relation to the social entity. So whilst we may say that macroscopic social entities do have causal influence on people, this influence will not be the same for everyone, because they have different histories and will experience different contexts.

We are thus developing a mechanism by which social entities have a causal influence on people, which is not the same as saying that social entities have causal influences on each other. In Chapter 6 we will further explore how this position differs from the complex realist position, whilst still asserting the reality of the social world and the importance of empirical evidence. This will be developed in relation to the third requirement of a basis for learning in complex systems: that our models and descriptions of social systems are situated within those systems.

3.1.3 Situating Models

Having situated our understandings as emergent from our brains/bodies, and in turn from our experiences within the social and natural world, we will be in a position to consider how the models[32] we develop of classrooms fit into this picture. The issue at hand is that throughout Chapter 2 we argued that models should be related to empirical evidence rather than supported by appeal to "analogy" or "metaphor" (see Davis & Sumara, 2006; Stacey, 2003a; Byrne & Callaghan, 2014). We also noted that complexity scientists develop models which have 'internal consistency' to other models, rather than a clear predictive capacity (see subsection 2.1.5). Yet we disallowed the implication from complex realists that some models are more realistic than others, on the basis of this necessitating a separation of our models and the phenomena they relate to (Section 2.3). The thorny problem we thus arrive at is how we account for the success of models in allowing us to describe, explain and predict what will happen in complex social settings. Once we have taken away any appeal to our models existing beyond the material world, or being able to replicate the dynamics of complex

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[32] The term 'model' denotes individual understandings but also written descriptions, graphical representations, mathematical abstractions and computational models, dance, music, painting, sculpture, etc. The criterion is that a 'model' is in some way a representation of a phenomenon in the real world (see Glossary).

systems (which are sensitive, nonlinear and dynamic) then it is not a simple problem to resolve.

We will show in Chapter 6 that the model of brain function developed (in Chapter 4) is able to explain how models can recreate important aspects of phenomena. This requires two steps. Firstly, we must recognise that models are real entities which have material basis in the brains that use them and their symbolic representations (words, equations, computer code, images etc.). This means that models are able to interact with the phenomena but also to influence people. Models and the social phenomena interact, so a model of a classroom both affects and is affected by that classroom. The second step however is recognising that the criterion of a good model is that we recognise it as similar to the phenomenon.

A photo might be seen as a better representation of a scene than a drawing. The pattern of light that is incident on one's eyes when viewing a photograph correlates more closely to the pattern of light from the 'real' scene than in the drawing. It is possible to have a model that recreates something of the original phenomenon, but this is not because of a supernatural link between the model and the phenomenon. Both model and phenomenon are real entities and they may have similar properties in some respect. A photo is formed from a pattern of light in the original scene and thus has a material relation to the scene at the point of its genesis. We must recognise however that we as observers conclude that the model and the phenomenon are similar in an aspect that we find important to us. A photograph promotes a similar pattern of light, but tells us nothing of the dynamics, smell, feel or location of what is in the image, nor how it might look from any other angle. In other circumstances a drawing may be judged as better, by highlighting certain features or perhaps providing a map of the scene.

We are thus able to recover the requirement that our models have empirical correlates. If a model recreates more of the original phenomenon then we will judge it as a better model. It is within the human realm that this judgement is conducted however; we recognise and judge the similarities in models and the modelled phenomena because our brains have evolved to recognise patterns. This will be developed further in Chapter 6.

Combining an ontological position which allows us to see that models are real entities, with the realisation that our brains recognise similarities, allows us to position our models as part of the complex social systems we inhabit. It also allows us to see why models which are empirically related to the phenomena at hand are likely to be better than those that are not: because they will likely replicate more of the patterns seen within the phenomenon.

Furthermore, whilst maintaining the importance of developing models which replicate more of the dynamics within the original phenomenon, we are able to recognise that the judgement of this is still a normative one. We can never recreate a complex social situation, but some of our descriptions are better than others.

In developing this first sketch we have covered a lot of ground quickly and throughout the rest of this chapter, and in the chapters to follow, we will lay out these arguments more clearly and with greater justification. In Section 3.2 we will develop the materialist position which allows us to situate our understandings and systems of symbolic language within the material world. In Chapter 4 we will then develop the model of brain function which explains how humans come to develop understanding of the world around us: how we learn. Chapter 5 will use these components to then explain why we are able to respond to, reproduce and manipulate patterns in the classroom. This will account for our shared understandings.

3.2 Deleuze's Materialism and Social Complexity

3.2.1 The World of Intensive Differences

In this section we will expand upon the initial sketch of a materialist position from subsection 3.1.1. We will do so by first outlining Deleuze's position (subsections 3.2.1 to 3.2.5) and then considering how it overcomes the difficulties that social constructionist accounts face (in 3.2.6) and the reliance upon a constant deferral of meaning in post-structuralist accounts (in 3.2.7).

In an interview, Deleuze says:

> "I feel myself to be a pure metaphysician.... Bergson says that modern science hasn't found its metaphysics, the metaphysics it would need. It is this metaphysics that interests me" (Villani, 1999, p. 139),

Deleuze aimed at a theoretical underpinning of contemporary science, but it is noteworthy that he drew upon notions from complexity science as it developed[33]. As such, we might read his challenges to ontological and epistemological accounts of philosophers such as Kant and Hegel as a suggestion that they are unable to support complexity science. We have already strayed into these 'metaphysical' discussions (e.g. in subsection 2.2.6) and must do so again in order to highlight the difficulties that can be overcome by drawing on Deleuze's system. This will in turn allow us to situate learning within classrooms without separating mind and matter in an untenable way and without accepting that meaning is constantly deferred and incomplete. However, we are not here aiming at a full description of Deleuze's work, instead seeking to interpret and 'translate' it for the purposes of considering social complexity.

In line with Derrida, Deleuze seeks to overturn reliance upon *identity* as being inherent in objects. That is, that the identity of a cup is to do with some inherent 'cupness' which our representations of cups capture[34]. In subsection 2.2.3, we saw that Derrida attempts to overcome identity by showing that a cup can only be defined in différance to a dynamic system of other identities. We also there proposed that the difficulty Cilliers inherits from this account is that meaning is always elusive because it is constantly deferred. Derrida claimed he was working at the margins of the philosophical territory staked out by Hegel, whereas Deleuze sought to take Hegel "head on" by constructing an alternative metaphysics (Marks, 1998, p. 16).

[33] For example Deleuze (1995, p. 29) decribes Prigogine's notion of bifurcation as an example of the "inexact but completely rigorous notions" shared by scientists, philosophers and artists.

[34] Such a view might be related to Plato's belief in ideal forms, which real objects are images of.

Deleuze's position is monist such that the world is "a univocity" constituted by "difference in itself" (Deleuze, 2004a [1968]). By this he refers to the 'substance' of the world as infinitesimal differences of two categories: *intensive* differences and *virtual* differences[35]. We shall explore virtual differences in subsection 3.2.5, here focusing upon how intensive differences allow for a materialist position.

Deleuze defines intensive differences as being what drives processes within the world. Intensive properties in science are those which 'cannot be divided' such as temperature. If a mug of tea at 70°C is divided into two volumes then each will remain at 70°C. The volume of the tea however is an extensive property; if there is 300ml of tea it may be divided into two cups of 150ml. Deleuze emphasises that intensive differences are often organised as critical points, a notion which is familiar to complexity science. Intensive differences thus constitute the points at which there is a qualitative change, the transition points in the world. Although we experience intensive difference, we conceive of it as subordinated to extensive difference: "we know intensity only as already developed within extensity, and as covered over by qualities." (Deleuze, 2004a [1968], p. 281).

The notion of the material world being constituted of "pure difference" is rather abstract. As noted in section 3.1.1 though, we can move it onto a firm grounding by relating it to a contemporary view from physics, such as that offered by string theory. Intensive differences are the infinitesimal differences which exist in the 'material' of the world.

3.2.2 The Image of Thought

We are yet to develop a position capable of overturning the inherent identity of objects however. To do so we need to account for how we understand the world of intensive differences, whilst being part of it. Deleuze argues that our understanding comes from our experience of the world. However, Deleuze situates this experience as prior to concepts:

> "The error of all efforts to determine the transcendental as consciousness is that they think of the transcendental image of, and in the resemblance to, that which it is supposed to ground" (Deleuze, 2004b [1969], pp. 120-121)

Deleuze is arguing against Kant's notion that our minds condition our experiences (Smith, 2009). For Deleuze, the empirical is the *immanent* experience we have of the world. Here, immanent is contrasted to transcendental, which Buchanan explains through analogy to a swimmer being able to navigate by the (immanent) currents they experience rather than the

[35] The terms 'virtual differences' and 'virtual causes' are used interchangeably within Deleuze's work.

(transcendental) stars (Buchanan & Webb, 2013). However, we must also include seeing and hearing things at distance in this 'immanent' experience, removing the connotation of physical proximity from the English word.

If there is not a separate realm of 'ideal forms' as Plato claims, and our experiences are not pre-conditioned by our minds, as Kant claims, then Deleuze must establish how we come to understand the regularities in the world through our immanent experience. He does so with appeal to the notion of a *multiplicity*. Within our empirical experience we encounter phenomena which are similar enough to be attributed to the same concept. Deleuze (2004a [1968], p. 2) paints a picture of this using the concept of a festival: each instance of the festival is entirely different yet the concept associated with the multiple instances is the same. A *multiplicity* is thus multiple instances of a similar experience. It is not defined by an ideal form, or pre-conditioned by the mind, but by the repetition of different instances which are nevertheless associated with the same concept.

> "Such an identity, produced by difference, is determined as "repetition". Repetition in the eternal return, therefore, consists in conceiving the same on the basis of the different." Deleuze (2004a [1968], p. 51)

This determination of identity is described as 'nomadic' in that it is not pre-determined. Deleuze gives the analogy of a mathematical set, whereby the members of a set are not determined by some universal rule but by evaluating a potential member as it is found. In Chapter 4 we will explore how the notion of the multiplicity can be both grounded and developed through the recognition that brains are conditioned by patterns in the world. Here though, we take from Deleuze the argument that concepts are not pre-determined but are the result of experience in the world.

This begs the question as to why we share the same concepts however, rather than all humans having vastly different ideas about the world. We might still maintain that in the above account concepts are prior to experience. Baugh (1992, pp. 139-140) explains that Deleuze recognises "vertical" relationships between the world and concepts, "horizontal" relationships between concepts and "diagonal" or "transversal" relationships to other conceptual systems. People experience the world but interpret it in relation to the conceptual systems already in place in society. Deleuze (2004a [1968]: Chapter 3) goes further however in describing an "image of thought" which contains the concepts that are drawn upon in describing our experiences[36]. Deleuze situates genuine thought as being able to contrast our immanent experiences to our existing conceptual frameworks: the image of thought. As Spangenberg explains of Deleuze's position:

> "Apart from the orderly, structured and representational way of our habitual thinking, there are always the chaos of chance happenings, and the irrationality and complexity of their ever-shifting origins and outcomes. We try to deal with the chaos and contradictory nature of pure difference by imposing structures, creating hierarchies, conceiving of things as 'the same' from one moment to the next, using definitions to limit meanings, and ignoring new and potentially creative experiences." (Spangenberg, 2009, p. 93)

We will return to how we come to have shared understandings in Chapter 5. Here however, it is important to distinguish between our thoughts being conditioned by ideal forms (Plato) or categories within our minds (Kant) and the notion that individuals come to utilise the conceptual system into which they are born and which is constantly developing. To Deleuze, dynamic systems of thought are materially constituted and condition individual understandings. This already provides an account of our understandings within the world being conditioned by both our experiences in the natural world, but also by our experiences in the social world. As such we see that learning in a classroom includes both interactions with the world and with accounts of it which are already in the social realm.

3.2.3 Immanence

In order to better understand the contribution of Deleuze's position in the development of complex materialism we will here situate it within a broader philosophical narrative. In this subsection we will consider how Deleuze derives his monist position of immanence and pure difference (see 3.2.1). In the next subsection we will explore how he develops his empiricism from which the 'image of thought' is developed (3.2.2).

Deleuze draws his monist position from Spinoza, who opposed Descartes' separation of mind and body. Spinoza develops "God and Nature" as pantheism and this leads to Deleuze's notion of a *plane of immanence*:

> "What is involved is no longer the affirmation of a single substance, but rather the laying out of a *common plane of immanence* on which all bodies, all minds, and all individuals are situated." (Deleuze, 1988 [1970], p. 122)

[36] Deleuze uses the image of thought primarily in relation to existing philosophical understandings.

Spinoza describes a dynamic world in which “the individual is not to be understood locally as a kind of point among points, but dynamically as a harmonization or divergence of more or less sympathetic regions of extension in motion” (Witmore, 2008, p. 106). Thus the distinction between an individual or object and its environment is blurred as both are in flux. Such a notion finds immediate appeal in relation to complexity theory in which form and structure are seen as dynamic and temporary. However Deleuze’s notion of immanence requires us to look beyond form and structure:

> “It is only when immanence is no longer immanence to anything other than itself that we can speak of a plane of immanence.” (Deleuze, 2005 [1995], p. 27)

Spinoza’s pantheism was furthered by Bergson, who distinguished the quantifiable from the ‘quality’ of experience. He argued that the world of objects and forms is constituted in extended space and is thus quantifiable. Bergson uses the example of a flock of sheep, which can be enumerated despite being a homogenous multiplicity, because they are distinct spatially (Lawlor & Moulard 2013). In contrast, our sensations are qualitative and pertain to a heterogeneous multiplicity which Bergson sees as fundamental in the world. This allowed him to consider time in relation to a qualitative change in sensation, which breaks with Kant’s view of time and space as being extensive.

To Bergson, time is not separated into quantifiable moments which are distinct from each other: past, present and future are part of the same *duration*.

> “pure duration excludes all idea of juxtaposition, reciprocal exteriority and extension” (Bergson, 1946, p. 192)

Famously Bergson became engaged in a bitter dispute with Einstein about the nature of time. However, as Canales (2005) highlights, Bergson did not deny the accuracy of Einstein’s theory of relativity but instead drew attention to necessary differences in perception which would accompany time dilation. Whilst Bergson’s conception of time was dismissed by scientists in the early twentieth century, it pre-empted aspects of quantum physics (de Broglie, 1941) and is instrumental in both complexity theory and in Deleuze’s ontology. As Osberg (2015) shows, the notion of emergence owes much to Bergson’s questioning of time as determinate and proceeding mechanistically.

Deleuze (1988 [1966]) derives the notion of ‘pure difference’ from Bergson, and the importance of intensive differences. However, Deleuze replaces Bergson’s duration with the *event* which is less reliant upon human sense. The notion of the event brings together

Bergson's duration with Spinoza's monism, as well as Leibniz's ideas on identity (Smith 2005). Deleuze thus distinguishes between historical time (Chronos) and the time of the event (Aion):

> "Whereas Chronos was limited and finite, Aion is unlimited, the way the future and past are unlimited, and finite like the instant." (Deleuze, 2004b [1969], p. 189)

We shall return to the notion of the event and how it might be enlisted in challenging representation in subsection 6.2.6. Here however we are able to see how Deleuze "tries to develop a metaphysics adequate to contemporary mathematics and science—a metaphysics in which the concept of multiplicity replaces that of substance, event replaces essence and virtuality replaces possibility." (Smith & Protevi, 2015)

We have already noted the possibility of replacing 'pure difference' with notions from string theory (see 3.1.1). We might also note Deleuze's frequent use of differential calculus to describe the infinitesimal qualitative differences in the world (e.g. Deleuze (2004a [1968], p. 57)). By adopting Deleuze's metaphysical system we are thus able to see how the world is constituted of a single, dynamic 'material', and how this is commensurate with contemporary complexity theory. In subsection 3.2.6 we will see how this monist position overcomes social constructivist views of complexity and in subsection 3.2.7 how it allows us to escape the issues of Cilliers' poststructuralist complexity account.

3.2.4 Empiricism

Finding a solution to the philosophical issues with existing forms of social complexity is essential in this thesis. However it is primarily about learning, and thus Deleuze's account of how humans develop an understanding of the world is central. In subsection 3.2.2 we considered the 'image of thought' and we are now in a position to situate this in the broader philosophical narrative that Deleuze draws upon, primarily the work of Hume and Nietzsche. We can now recognise the importance of difference and repetition, and the origins of this in Bergson's account of sense making:

> "sensations and tastes seem to me to be objects as soon as I isolate and name them, and in the human soul there are only processes. What I ought to say is that every sensation is altered by repetition, and that if it does not seem to me to change from day to day, it is because I perceive it through the object which is its cause, through the word which translates it." (Bergson, 1913, p. 131)

Whilst Bergson's account joined a Hegelian ontology in phenomenology and structuralism (Osberg 2015), Deleuze instead linked it to Spinoza's monism and Hume's empiricism to develop an account of thought beyond human sensation alone. Deleuze takes from Hume the emergence of understanding from the difference and repetition of experience:

> "The principle of habit as fusion of similar cases in the imagination and the principle of experience as observation of distinct cases in the understanding thus combine to produce both the relation and the inference that follows" (Deleuze, 2005 [1995], p. 41)

Understanding emerges from the qualitative multiplicity, the 'pure difference' of experience. However, as noted in 3.2.2, Deleuze also recognises social aspects of learning. He explains how 'human nature' involves identities, relations and institutions as 'artifice'. Through reading Hume, Deleuze claims, we are able to see that both identities and relations are external to each other. In a monist world which is in flux we see that our understandings are not fixed or related to some other realm of knowledge but are constantly changing through our experience.

> "Thus the entire question of man is displaced in turn: it is no longer, as with knowledge, a matter of the complex relation between fiction and human nature; it is, rather, a matter of the relation between human nature and artifice (man as inventive species)." (Deleuze, 2005 [1995], p. 47)

Our empirical experience within the world conditions our 'passions' and 'tastes' as well as our understandings: we learn from the world around us. However, in drawing on Nietzsche, Deleuze shows that we need not return to a determinist view, nor do we replace fixed identities (Being) with an intractably dynamic world (Becoming):

> "Becoming is no longer opposed to Being, nor is the multiple opposed to the One (these oppositions being the categories of nihilism). On the contrary, what is affirmed is the One of multiplicity, the Being of becoming. Or, as Nietzsche puts it, one affirms the necessity of chance." (Deleuze, 2005 [1995], p. 86)

It is this *affirmation* which allows us to have agency in the world. In considering Nietzsche's eternal return: the prospect of time repeating itself, we are forced to affirm the world we experience, but "Nietzsche's secret is that *the eternal return is selective*" (Deleuze, 2005 [1995], P. 88, original italics). Deleuze takes from Nietzsche the 'Yes' of affirmation which will be important in opposing it to Derrida's deferral of meaning inherent in Cilliers' account (see subsection 3.2.7).

In introducing Deleuze's final work, Rajchman suggests that Deleuze's 'last message' came at a time when philosophy was facing difficulty:

> "As with Bergson, one needed to again introduce movement into thought rather than trying to find universals of information or communication – in particular into the very image of the brain and contemporary neuroscience." (Rajchman 2005, p. 20)

In drawing on Deleuze's work, and its philosophical lineage, this thesis develops a dynamic view of thought, and learning in particular. One which rejects universals and yet does so through drawing on contemporary neuroscience to show that Deleuze's ideas can be made concrete and practical.

3.2.5 Virtual Differences

Deleuze challenged, on a philosophical level, accounts of our understandings as related to some other realm or *a priori* categories of reason. In developing this challenge he used the notions of intensive differences, from which our understandings emerge, but also of virtual differences, to which we now turn. We will focus upon two reasons that Deleuze relies upon virtual difference: firstly to allow us to overcome the need for a separate world of 'possibilities', which is no longer permissible in a materialist account, and secondly that it allows for human agency. These functions are both important to an account of how people act within complex social systems such as classrooms. We will therefore explore Deleuze's virtual causes here, but with a view to ultimately overcoming their metaphysical character and providing a more concrete account of human agency in this thesis.

In a dualist or dialectic metaphysics there can be a world of possibilities, in which the actual world follows one particular path. In a monist system this realm of possibilities is disallowed, so the world is not one actuality in a sea of possibility: it is all there is. As Smith (2009) notes, Bergson proposed that we wrongly assume that nonbeing exists before being, and Deleuze takes up this objection as he derives his position from Bergson (see 3.2.3). In Deleuze's system, virtual differences thus replace 'possibilities' by providing something within the material world which might allow novel forms and ideas. DeLanda (2002, 2011) makes the virtual more concrete by describing "capacities" and "tendencies"[37]. For example, water has the tendency to evaporate if heated above 100°C (at atmospheric pressure), but chemical elements have the capacity to form novel combinations with other elements (DeLanda, 2002, p. 62). This provides a useful starting point for dispensing with a separate realm of

[37] We will draw on DeLanda's interpretation of the virtual in relation to models, in subsection 6.1.2

possibilities. Material entities have capacities and tendencies which play a role in how they interact and develop, so novel forms are allowed without being pre-existent possibilities.

Deleuze however seems to be using virtual differences in relation to human agency in a way that DeLanda does not fully capture. As Williams (2006) argues, historic situation is more important in Deleuze's work than in DeLanda's 'translation' into scientific terms. Smith (2009, p. 34) explains that to Deleuze "A virtual idea is not a condition of possible experience, but the genetic element of real experience." This endows virtual causes with a way of both avoiding 'possibilities' and being related to agency. Consider the claim that:

> "*The virtual is fully real in so far as it is virtual*. Exactly what Proust said of states of resonance must be said of the virtual: "Real without being actual, ideal without being abstract"; and symbolic without being fictional." (Deleuze, 2004a [1968], p. 260) [original italics]

The reference to Proust presents a way into thinking of the virtual. Ansell-Pearson (2005) describes the narrator in Proust's *À la recherche du temps perdu* contemplating how aspects of the present, such as uneven paving stones, prompt the recall of a place such as Venice. The memory of Venice does not contain the paving stones in the present, yet the coming together of the memory and the present creates a reaction in the narrator. Deleuze sees in this the 'crystallisation' of the past in the present such that when the virtual difference is actualised it evokes the idea of Venice. In language familiar to complexity theory, we might say that the virtual allows the importance of the historic path that a system has taken: an indiscernible difference which may influence the future trajectory of the system. Yet in being 'virtual' we do not need to ascribe the idea of Venice to some other realm, the virtual is present[38] in the real world. Virtual difference therefore is constantly ready to be actualised but is not a property of intensive or extensive differences, nor is it some dualist 'possibility', it is "real without being actual".

Deleuze & Guattari (2004b [1980]) later use various devices for elucidating the virtual, the most powerful of which is the "Body without Organs" (BwO). They attempt to isolate the notion of 'body' from the sum of all organs, thus creating a concept which is both inseparable from material reality (in this case the organs) but is nonetheless a (virtual) entity in itself.

[38] As noted in subsection 3.2.3, Deluze's notion of *event* overcomes a linear notion of time. Badiou (2006) draws attention to the implication that either there is no present or that all is present. This speaks to nonlinear causality and will be expanded upon in 8.3.2.

Another example they use is to illustrate this is ‘capital’, which is inseparable from ‘capitalism’ and from ‘commodity’ but is nevertheless not equal to both. Again, the notion of capital is something which exists only as part of other concepts, but is nevertheless formative in how these concepts develop.

> “Thus, BwO is indeed a unity, but not a unity in the traditional metaphysical sense – namely, a unity whereby diverse elements are gathered by a transcendent and/or privileged element (e.g., the judgement of God). Thus, the BwO in not an other which restores a lost unity or presence; it is a ‘strange unity’ whereby ‘anarchy and union are one,’ or it is the consistency necessary for the emergence of identifiable, non-strange unities.” (Bell, 2006, p. 162)

Within this thesis we will ultimately overcome the need for virtual differences by showing that concepts such as capital or body, or the recall of Venice, can all be accounted for by the conditioning and response of the brain within the real world (see subsection 4.2.3). We cannot dismiss virtual causes out of hand however. Firstly, any materialist mechanism for social learning must also be able to account for how humans can be inspired by past events and experiences, which stimulate creative processes in the present. We will show that this can be recovered from an account of brain function. Secondly however, we must recognise the role virtual difference plays in accounting for possibilities in a materialist frame.

We will not engage fully with whether Deleuze’s metaphysical system is able to do away with a world of possibilities, or whether DeLanda’s capacities and tendencies are sufficient to explain this in the broader world. What is of direct relevance to this thesis is the need for any account of learning within a social system to allow that past experiences might influence the present, and for human agency to situated within complex systems. We will show (in Chapter 4) that this may be achieved through the recognition that our brains have been conditioned by experience, so past events shape future response. Furthermore, the relation between experience as manifest in our brains and the fine detail of a specific context means that novel thoughts and behaviours are always possible. Whilst we shall develop it only in relation to human understandings in this thesis, complexity theory thus provides a way of accounting for the novelty of human understandings and action. Human agency can be related to the emergent response of brains within the material world, without reducing that agency to a mechanistic or deterministic process. The importance of both considering and overcoming Deleuze’s notion of virtual differences in this thesis is in being able to situate human individuality and creativity in complex social systems.

3.2.6 Materialism versus Social Construction

Before we develop more concrete mechanisms for learning in classrooms, it is worthwhile here exploring how adopting (and adapting) Deleuze's metaphysical system is already able to overcome some of the issues faced by existing accounts of social complexity, as explored in Chapter 2. Here we will argue that a materialist position resolves the untenable separation of mind and matter that social constructionists rely upon (expounded in Section 2.4). In the next subsection we will deal with the unpalatable notion from post-structuralist complexity thinkers that meaning is constantly deferred and can never be resolved (from Section 2.2).

In Section 2.4 we used Stacey's (2001, 2003a, 2003b, 2005) notion of "complex responsive processes" to show the incommensurability of social construction and complexity theory. Drawing on Mead's (1934) description of 'significant symbols' which allows a capacity of an individual "I" to anticipate a social "me", we saw that in a complex system it is impossible to distinguish between individual and social aspects of mind, because they must both be part of the same dynamic and nonlinear system. Equating the individual and social either removes the agency of individuals or it removes any sense in which the social is greater than the aggregate of those individuals. The 'Hegelian logic' of this, which Stacey inherits from Mead, only serves to make the argument even less convincing.

As well as failing to adequately explain what constitutes the social world though, social constructionist accounts fail to deal with the influence of the real world in shaping our understandings. If we admit the reality of the world, and we must, then we must also admit that humans are able to learn outside of social interactions. Our understandings are influenced by both the natural world but also by interacting with human artefacts such as architecture or ancient texts, which are difficult to classify as social interactions. The issue at hand therefore is that in attempting to equate the social world to our minds, social constructionists are unable to situate these minds within a real world.

A monist and materialist position inspired by Deleuze cuts straight through this, by upholding a 'flat ontology' in which our understandings have a material basis. As noted we will provide a specific process for this shortly, but at the philosophical level we can already see that if our understandings are treated as material entities then there is no issue with a complex interaction between the rest of the world and these understandings. Deleuze's (2007) term "hodgepodge" gives us a way of denoting the heterogeneous elements of a classroom: people, music, textbooks, conversations, ideas, videos etc. If ideas and social interactions are seen as ontologically different from textbooks and videos then we would require a convincing account of how the world of ideas and the material world influence each other in nonlinear and dynamic ways. It is not only impossible to distinguish between mind and matter in such an account, it is highly anthropocentric to assume that only conscious animals have access to this separate world of ideas. Situating mind as material, as Deleuze does, brushes away these issues in one sweep.

What about human agency though? How can material alone account for the creativity and individuality of humans, or our capacity to plot, plan and scheme? Again, the answers will come when we flesh out how humans interact with their environment, drawing upon their past experiences. Deleuze uses virtual causes to account for human agency and creativity, and in situating these virtual causes as material he allows for minds to be creative without appeal to a supernatural realm. In Chapter 4 we will expand on the contention that the unique histories of individuals allow them to have unique interactions with the specifics of a context, without the need for virtual causes. Complexity allows that novel understandings may develop though complex interactions within the world[39]. In accounting for human originality there is no need to appeal to divine inspiration, absolute Spirit, ideal forms or cosmic self-realisation.

3.2.7 Materialism versus Deferred Meaning

We have argued that a separation of mind and matter is not tenable in a complex system, because there can be no boundary between them. This echoes the concern of post-structuralist thinkers that the world and our understandings are not related by simple, fixed relationships. We saw in subsection 2.2.3 that Derrida objected to 'representation', that is, the assumption that our thoughts and language correspond directly to features of the real world. Cilliers develops this by showing that our linguistic systems can be seen as networks, in which the meaning of a term can only be resolved in relation to all other terms. Furthermore, these networks are dynamic and therefore can never be fully resolved. Cilliers describes a system in which meaning is constantly deferred and he opposes the possibility of absolute truths in favour of recognising meanings as contingent and bounded (see subsection 2.2.5).

Despite a capacity to explain the limitations of understanding and the importance of context within a classroom, the post-structuralist account was found lacking in a number of ways. Firstly, if meaning is constantly deferred then how are we ever to decide how to act in a classroom? Similarly how can we position learning if full understanding is never achieved? Cilliers' appeal to making bounded and contingent statements fails to resolve this, as defining

[39] This holds whether we see the world as fundamentally random or simply too complex to comprehend (see subsection 1.2.4),

boundaries is itself problematic. Secondly, we showed that Derrida's account fails to fully escape the untenable Hegelian notion of negation within a dialectic system (subsection 2.2.6). By showing that meaning is constantly deferred Derrida, and by association Cilliers, 'blocks' any resolution of the dialectic relationships that Hegel describes, but these relationships are not disposed of. Thirdly, by considering language, meaning, and human relationships as complex networks, Cilliers is not able to see the differences between these systems or how they interact.

Having now described Deleuze's position, we are able to uphold Marks' (1998, p. 16) argument that Deleuze takes Hegel "head on", and to see the difference between this and Derrida's deconstruction:

> "It is the difference between playing a Derridean game you can never win and a Deleuzean game you can never lose. It is the difference between No and Yes." (Bearn, 2000, p. 441)

Derrida and Deleuze both reject the existence of fixed relationships between our understandings and the world. Cilliers develops Derrida's position by arguing that meaning is emergent from a dynamic network of relationships. So in a classroom, we might take this on the conceptual level of an individual child and say that a new concept must be related to all the other concepts that a child holds and becomes part of their dynamic system of understanding. Alternatively on a whole class level, we might say that a particular child's understanding develops within a dynamic network of understandings within the class. As we have already concluded, Cilliers is not clear about the specific system we are to apply this philosophical system to. The point however is that the meaning of a concept, or the learning of an individual, can never be fully resolved: we cannot make affirmative statements about a child's understanding. This is what Bearn is referring to as a Derridean game you can never win: to make a claim about learning you must understand the full complexity of the specific context, and this is impossible.

In outlining a materialist position we must also recognise the role of context; indeed the insight from complexity is that context can never be ignored. However, because Deleuze sees concepts as emerging from our "immanent" experience we can see the understanding a child has as a real entity in its own right. The understanding has emerged, within a specific context, but we do not need to see it as incomplete or unresolved: it exists. Here affirmation, the Yes, which Deleuze derives from Nietzsche become important (see 3.2.4). We are still very much working in the abstract here and over the rest of this thesis we will clarify how we can see an understanding as a material entity and provide a model for how they emerge: how learning takes place (Chapter 4). The intention here however is to show how adapting Deleuze's position allows us to escape the philosophical issues faced by Cilliers' account: that meaning can never be resolved; that we do not escape a Hegelian metaphysics; that we cannot be specific about the systems involved.

Let us reconsider Cilliers' use of a neural network as analogous to Derrida's system of trace and différance (subsection 2.2.3). Cilliers (1998, 2010) argues that in such a system, where traces are analogous to the weighting of neural connections, we cannot see meaning as related to the specific nodes within the network; it is instead distributed across the system. As noted, it is not clear which network Cilliers is talking about, but if we take an individual child to be a node in a network, we see that the understanding that the class has of a problem/situation cannot be assigned to any one child. The mistake Cilliers makes however is in therefore arguing that meaning is constantly deferred and is unresolvable: in following Derrida he gets caught up in rejecting meaning entirely.

> "Derrida is unable to say Yes, because he thinks Yes must always have a point. He does not realize that the true Yes is pointless." (Bearn, 2000, p. 441)

In arguing against our understandings being fixed representations of the world Derrida, and in turn Cilliers, sees our understandings as ephemeral and meaning as intangible. Deleuze does not deny that understanding is dynamic and fleeting, but he positions it as real. New understandings are determined by our experiences and existing understandings within specific contexts. We do not need to deny the existence of meaning at all, or defer it indefinitely. At a specific moment within a classroom each individual person will have a specific understanding, and the class as a whole will have what we might call an 'understanding': a macroscopic response to the situation at hand. Whilst we will later flesh out what this means in relation to individuals (Chapter 4) and classrooms (Chapter 5), here we see that the response of a pupil, or of a class as a whole, is real and context-specific.

Whilst we will not here enter into a full discussion of how Deleuze's system overcomes Hegel's dialectics, we must explain briefly how it overcomes notions of fixed identity and surpasses Cilliers' post-structuralist account of complexity. Ellrich's (1996) critique of Deleuze will provide a jumping off point for this. He deconstructs Deleuze's reliance upon the notion of 'difference in itself' or 'pure difference' and concludes that for there to be a difference then the very concept of difference must have some fixed identity. However, Bell (2006) points out that Ellrich (and by extension Derrida) are missing the way in which Deleuze considers identity as part of a dynamic system. Ellrich assumes some correspondence between an experience and the meaning it is given, in the same way that a blueprint corresponds to a building. Rather than assuming a simple relationship between phenomena and understanding, Deleuze & Guattari make reference to 'genetic causes', in parallel to the way in which an organism need not resemble its genetic material (Deleuze, 2006 [1962]; Deleuze & Guattari (2004b [1980], p. 59). People experience the world but interpret it in relation to the patterns of understanding already in place, mediated through the shared biology of human perception. In this way Deleuze has released concepts from networks of relations, but still characterises understanding as emergent. The nature of relations as autonomous entities is brought into question.

By considering multiplicities Deleuze focuses on the development of concepts from a series of unique experiences which are 'repeated'. In Deleuze's system we are able to affirmatively denote something from our empirical experience: meaning emerges in the moment. To illustrate this consider how we might identify a pigeon. By Derrida's account, its identity would depend upon its relation to all other birds and indeed other species in the ecosystem. Pigeon number 101 is not a magpie nor a parrot or a cat and it is not the same as pigeon 102. However Deleuze allows us to see that by 'experiencing' a series of pigeons, even if we had never seen a bird before, we would be able to associate the utterance 'pigeon' with this series of experiences. Furthermore pigeon 101 would be a unique instance of the concept of pigeons, first experienced in a particular context. Whereas a Derridean viewpoint would contest that we are not able to assign any fixed identity to individual pigeons, the Deleuzean viewpoint suggests we do not need to, because it is our immanent experience that generates understanding.

As both Marks (1998) and Hayden (1995) argue, Deleuze succeeds in meeting Hegel head on. We do not need a dialectical system in which meaning must be resolved, but nor do we need to appeal to a separate world of ideal forms as Plato does, or the pre-conditioning of our experiences as Kant suggests. By positioning human understanding as a part of the material world we are able to develop an account of social complexity which overcomes the issues faced in the existing literature (detailed in Chapter 2). Our understandings are emergent and dynamic, and so too is the macro-level response of a social entity such as a class to its environment. Deleuze's position has a number of advantages over Derrida's as a foundation for complexity thinking. Whilst not denying the dynamic or contextual nature of meaning, Deleuze is able to break free of the need for constant deferral of meaning or appeal to a network of relations.

3.3 Chapter Conclusion

This chapter has outlined a materialist position and has also begun to show how this position overcomes the issues faced by other accounts of social complexity. Section 3.1 provided a first sketch of the arguments which will be developed across the rest of this thesis. There are three aspects to this, which answer three issues arising from our evaluation of existing literature in Chapter 2: an account of the role that the real world plays in developing our understandings, a description of how our understandings relate to the real world and an account of how our models and understandings are themselves within complex social systems. Each of these was dealt with in turn, to orientate the reader and to introduce the solutions at first approximation.

The position outlined, which we have called complex materialism, adopts Deleuze's 'flat ontology' by arguing that our understandings should be seen as part of the material world. The initial sketch of this within subsection 3.1.1 was developed further in Section 3.2 in relation to Deleuze's monist system, and its lineage within philosophical thought. Whilst we noted what needs to be made more concrete in our account so far, what is to be sustained is that our concepts are not related to a supernatural realm but arise from our experiences in the world. By seeing the heterogeneous elements of classrooms as having a material basis we see that experience of the social world is not ontologically different from experience of the natural world. Our experiences thus allow novel thoughts as well as existing patterns of understanding. As such, we approach an account of classroom learning, the development of understanding, as being emergent from the interplay of experience and existing conceptual systems within the classroom. This account is commensurate with complexity as it sees learning as emergent from interactions within the material world, but rejects any fixed or predetermined link between our understandings and that world.

In subsection 3.2.6 we showed that seeing our understandings as material immediately addresses the problems that social constructionists (such as Stacey) have. Individual understandings and social understandings need not be related by a dialectical relationship if we see both as part of a material world. The social world is made up of individual understandings as well as symbolic artefacts, but both can be seen as having a material basis. Thus, learning is the interaction of brains with the real world; it is material interacting with material, which is unproblematic.

The overcoming of the issues faced by post-structuralist accounts (such as Cilliers') was not so straightforward, as we had to account for how meaning is contextual and how Hegelian metaphysics is overcome (subsection 3.2.7). Under Deleuze's system we do not need to defer indefinitely to a dynamic network of relations which place understanding outside of our reach. Instead, we see that understandings emerge from specific contexts, but are nevertheless real entities. This means that the understanding of an individual child or the behaviour of a particular class can be treated as part of the material world. Whilst the dynamics are completely different, a child's understanding of a classroom does not need to be assigned a different ontological category to a complex chemical system or the weather. Whilst we can never know them precisely, they can be investigated, influenced and described as aspects of material reality.

As such we have developed a materialist position and linked it to complexity theory, as well as showing how this overcomes some of the issues in the existing literature, namely the social constructionist position and post-structuralist complexity position. However, there is still much work to be done in defining complex materialism and evaluating it in relation to classrooms. We are yet to answer the difficulties that complex realists have in situating their models, or provide a firm basis from which complexity science may proceed in relation to social settings. Both of these will be reconsidered in Chapter 6.

Firstly however, we will turn to the problems of how we can consider our understandings to be material. Deleuze's position suggests that understandings are emergent from the material world, and therefore has the potential to provide a theoretical basis with which to underpin complexity theory. Conversely however, contemporary complexity theory has the capacity to both further the philosophical discussion begun by Deleuze, but also to provide specific descriptions of the processes involved. In Chapter 4 we will account for the relation between brains and the world they experience. Doing so will overcome the notion of virtual causes that Deleuze relies upon in relation to human agency. In Chapter 5 we will then develop an account of how we can see "the image of thought" as material. Together, Chapters 4 and 5 will not only support the theoretical position of complex materialism outlined in this chapter, but will also allow us to develop an account of learning within the classroom.

4 Learning as a Complex System

4.0 Chapter Introduction

Complexity theory poses a challenge to any position which situates our understandings as outside the material world. In Chapter 3 we argued that a materialist position overcomes the issues of seeing the mind as a social entity as social constructionists do (Section 2.4) and also the issues of deferred meaning which trouble post-structuralist accounts (Section 2.2). Whilst seeing understandings as emergent from the material world answers questions on the philosophical level, what is required is a more specific account of how this can be the case. If we characterise our understandings as material then what form do they take, where do they reside, how do they develop? We will explain how our understandings can be seen as material in two senses. Firstly, in this chapter we will model understandings as electrical patterns within brains, embodied within human behaviour and response. Secondly, in Chapter 5 we will show how our understandings are manifest in the material of the human sphere: our symbolic language; media; artefacts; technologies. We will thus explain how understandings emerge and develop within the material world.

In Section 4.1, we will draw upon Cilliers' (1998, 2005) model of complex neural networks to show how this provides the basis for a model of individual learning as the adaptation of neural networks within the brain. We will explore how such a model allows us to see learning as the adaptation of brains to classroom contexts. Whilst this thesis contains no primary empirical evidence, by drawing on neuroscience, cognitive science and child development we will build the case for a material account of learning within classrooms. Furthermore we will overcome the need for virtual causes in Deleuze's system.

In building such a case however we must be mindful of two things. Firstly, that the process by which a specific pupil learns within a specific context will be unique. The insight from complexity is that the historic detail of a system as well as the minutiae of the context at hand may lead to novel processes (this was introduced in subsection 1.3.1). Whilst we will propose a model of brains and behaviour adapting in relation to the context of classrooms, the way that learning takes place within a specific classroom can only be described through investigation of that classroom. In this thesis we can only propose tentative and general models.

This brings us to the second point we must be mindful of: that we are proposing models. In Chapter 6 we will develop further the relation between models and the systems they model.

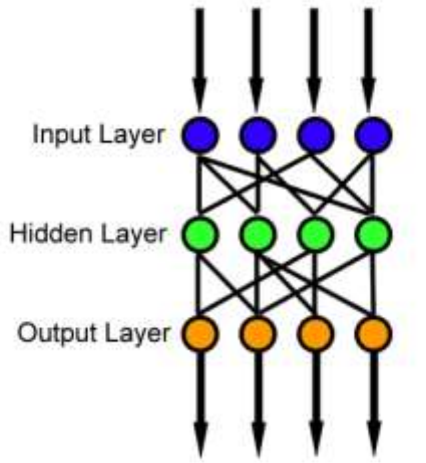
Here we must recognise that the details of the model we propose in this chapter will likely be challenged over time as new empirical evidence is developed. However, the salient point is that a materialist model can be developed which recognises the context-specific and dynamic nature of learning within classrooms. Furthermore, this model allows the insights from complexity theory to be brought to bear on classroom learning.

4.1 The Brain as Complex

4.1.1 The Brain as a Neural Network

In subsection 2.2.3 we saw how Cilliers related artificial neural networks to Derrida's deconstruction. Here we will focus upon how Cilliers draws on experience as an electronic engineer in developing a model of human brains as artificial neural networks. This will allow us to take first steps in proposing a process for how human understanding adapts to the material world and can itself be considered to have a material basis.

Fig 4a – Representation of a simple feedforward network.



To explain how neural networks adapt, Cilliers (1998) gives an example of a computational neural network which may be 'taught' to convert present tense verbs to past tense. A present tense verb is presented as the input to the network, and the correct past tense verb is presented as the output. Between the input and output layer of nodes there is a sufficiently large number of interconnected nodes through which a signal may travel. The operator then adjusts the strength of the connections (by adjusting the electrical conductivity) until the input of a present tense verb leads to the output of the associated past tense verb. This is not by programming the rules of tense into the system: it is by adjusting the network until the right answer is produced each time a new verb is presented. In this sense the 'training' is a process of trial and error, although an algorithm is often used to reduce the error at each node.

Once this system has been trained it is able to make an 'educated guess' at output from previously unseen input; it responds based on its structure. In this way the abilities of a network are determined by the weights of connections between the input and output layer. Cilliers describes such a network as a 'feedforward' network and represents it diagrammatically as a series of node points joined in layers from the input to output layers (see Figure 4a). This type of network is 'trained' by altering the strength of connections until it converges on a solution. After the training phase however, these networks are able to continue 'learning' because the strengths of connections continue to be adjusted by their usage within the system.

As noted in subsection 2.2.3, neural networks do not have rules or predetermined programs: they simply respond according to the internal structure of the system and are able to recognise patterns. As such, neural networks have applications in sales and marketing forecasts (Kuo & Xue, 1999) and image processing, for example Johnson & Hogg (1996) show how a system can be trained to predict where a person will walk. Cilliers' account of a simple feedforward network does not fully account for these 'real life' systems however and provides a very simplistic view of artificial neural networks. Even a relatively simple number plate recognition system (Draghici, 1997) requires feedback between different aspects of the system and a sufficient level of interconnectedness to ensure a reliable output.

Nevertheless, such networks have relevance to human learning. Consider Elman's (1995) work in which neural networks were trained to predict the next word in a sentence, using a set of 10,000 sentences, drawing on 29 nouns and verbs. Of particular interest here is the network structure after training, which revealed internal dynamics that reflected differences between nouns and verbs, but further into animate and inanimate nouns and transitive, intransitive and optionally transitive verbs. However, it also displayed differences in how it responded to words in different contexts (e.g. boy as subject vs boy as object).

> "Thus, a network state did not correspond to a word per se, as a traditional representational analysis might expect, but rather to the outcome of processing a word within a particular context." (Beer, 2000, pp. 91-92)

This means that a relatively simple artificial network displayed what Cilliers terms 'distributed representation'. There is a correspondence between the world and the structure of the network which responds to it, but it is not a straightforward correspondence. The representation is distributed across the network such that no specific node or neuron can be seen to correspond to an aspect of the input, nor is a linear process or equation determining the way the network responds. The system learnt through engaging with multiple examples and was then able to use its internal structure to respond to new information, without drawing on predetermined rules. It also has implications for considering the role of context in learning, which we will develop shortly (subsection 4.1.5).

Here it is noteworthy that considering the brain in this way echoes Deleuze & Guattari's (2004b [1980], p. 59) contention that experience be seen as a 'genetic cause' in the sense that our brain structure does not replicate experience in a simple way (see 3.2.7). The current state of a neural network when it receives new stimuli will influence how the network adapts and therefore the history of the network/learner is important. Furthermore, the network/learner will respond to stimuli in the broadest sense, so the context is important. For example, when looking at a scene the background would influence the response as well as objects in the foreground; when identifying a word, tone and volume are important. Whilst the model needs further development, it is already possible to relate human learning to a material process in which brains adapt within specific contexts. We also see that our understandings do relate to the real world but should not be seen as truths in which we have accurate representations of reality.

Accepting, for the moment, that the first sketch of neural networks presented above is incredibly simplistic, we need to consider whether this relates to learning in humans. Cilliers notes that the field of artificial neural networks grew from early understandings in neuroscience and that the fields have continued to develop in reference to each other, although exploration of artificial neural networks has also developed as a field in its own right. Primarily, artificial neural networks are based upon the work of Hebb (1949) who proposed a physiological basis for learning (Grossberg, 1982).

4.1.2 Hebb's Law

Hebb's law proposes that through continued stimulation of one neuron by a nearby neighbour, the efficiency of the path between these two neurons is increased. Computational scientists have used this as the principle for developing models of neural networks in which a number of neurons are joined at 'nodes'. The nodes can be designed so that they respond to an electrical signal in a specific way. For example, the electrical signal from an input neuron could be continuously added to previous inputs, to provide a growing signal at an output neuron. In this way the neuron models Hebb's law by increasing its output according to further input[40]. Thus, artificial neural networks provide models for how learning takes place within the brain.

> "Clusters of information from the external world flow into the system. This information will influence the interaction of some of the components in the system – it will alter the values of the weights in the network. Following Hebb's rule… if a certain cluster is present regularly, the system will acquire stable weights that 'represent' that cluster, i.e. a certain pattern of activity will be caused in the system each time that specific cluster is present. If two clusters are regularly present together, the system will automatically develop an association between the two. For example, if a certain

[40] Most commonly however, more sophisticated 'nonlinear transfer functions' are used in computational models to represent the functioning of neurons and it is these that are adjusted in the training phase of an artificial network.

state of affairs regularly causes harm to the system, the system will associate that condition with harm without having to know before hand that the condition is harmful." (Cilliers, 1998, p. 93)

Here Cilliers describes how Hebbian learning occurs in a neural network and how feedback allows a system to develop 'meaning' such as harm, without that being predetermined. There are two further points of interest here: firstly, Cilliers' use of inverted commas in describing representation indicates his argument around distributed representation (see last subsection). Secondly, the use of the word *clusters* to describe information is not developed by Cilliers, but we will relate it to patterns in the material world in Chapter 5.

If we are to adopt such a model for human learning however, as Cilliers does, we need to first of all question how well Hebb's law is supported by contemporary neuroscience. Whilst Hebb (1949) postulated that 'synaptic knobs' joining the two neurons developed or got larger in association with this increased association, it was later shown that chemical neurotransmitters are responsible for transferring signals between neurons. This does not contradict Hebb's law, but the association of synapses must be related to increased production of neurotransmitter by the pre-synaptic neuron or increased sensitivity by the post-synaptic neuron. Antonov et al. (2003) have shown that in Aplysia (a marine gastropod), synaptic association may be described as Hebbian. Sylwester (1995) suggests that Hebb's law can be associated with the development of dendrites[41] on the post-synaptic neuron, which allow a greater amount of neurotransmitter to be detected and cause the neuron to fire more readily.

Gazzaniga, Ivry & Mangun (2002) report studies in rabbits that support such mechanisms and in mice it has been possible to chemically block the increase in strength of such neural pathways, termed as *long-term potentiation* (LTP), leading to the mice not being able to form new spatial memories. However, they caution that further studies (e.g. Sauceier & Cain, 1995) have found that these chemicals did not prevent mice that had been pre-trained to swim to a platform from adapting this strategy to swimming to a platform in a maze. The implication is that the post-synaptic receptors were important in devising strategies but not in creating new maps using those strategies.

Further research suggests that it is not just individual neurons, but groups of neurons which adapt. Freeman (1994b) argues that when a rabbit learns to respond to stimulus, there is

[41] more accurately N-mthyl-D-aspartate (NMDA) receptors.

irreversible change in only some synapses[42], which leads to a heightened sensitivity of groups of neurons. Edelman (1993) supports this in arguing that learning is associated with the modification of populations of neurons:

> "Synaptic changes do not represent information that is stored in individual connections between single neurons, as in connectionist models. Instead, signals act, often heterosynaptically, to select variant populations of synapses that connect cells within and between neural groups" (Edelman, 1993, p. 117)

Edelman is arguing that in connectionist models, such as Cilliers', there are hundreds of neurons which adapt individually. However in the human brain there are billions of neurons and selection is at the group level. Whilst this challenges the reliance of artificial neural network models on Hebb's law, it does not undermine an account of brains as adaptive to experience.

Even study of artificial neural networks has suggested that Hebb's law alone cannot account for learning: there must also be a mechanism for neural pathways becoming weaker if they are inactive. This allows the system to 'forget' and provides the necessary plasticity to adapt to new situations. Hebb's law has been modified within what is known as BCM theory to include such mathematical functions (Bienenstock, Cooper & Munro, 1982). Such models of neural development remain at the forefront of neuroscience and as such Cilliers' connectionist model of learning, which he applies to human brains, is tentatively supported by contemporary neuroscience.

Despite being a tenet of neuroscience since the 1950s, Hebb's Law still has not accumulated a large amount of scientific evidence to support it. This is likely due to the experimental difficulties of seeing neural development within a living creature (Freeman, 1994a). Whilst artificial neural networks, based on Hebb's law, are undoubtedly much simpler than human brains, there is evidence from experimental work that the brain adapts to stimuli in a sophisticated way.

4.1.3 The Brain as a Complex Adaptive System

It is clear that human brains do not behave in the same way as the simple neural networks that Cilliers builds his arguments upon. So is it reasonable to consider the brain as a complex adaptive system? The European Union have recently launched a huge project, costing 1.2

[42] Those between the excitatory neurons but not between input and excitatory neurons.

billion euros, into the workings of the human brain[43] and there is still considerable work to be done in developing models of how the human brain learns. As such, this thesis does not attempt to develop a comprehensive model for brain function. Instead, we are here concerned with demonstrating that it is plausible to model the brain as a self-organising, complex system and that this is able to account for learning within a materialist frame.

It is apparent that artificial neural networks, mathematical models and experimental works with animals are being brought together in understanding learning as the self-organisation of brains as complex systems. Syntheses of works in these different areas, such as those by Arbib (1995) and Reimann & Spada (1995) show that although there is much to be learnt from each field, there is as of yet no convergent understanding of how brain function is related to learning. This is not surprising if we consider the complexity of the brain and of human consciousness, as well as our appreciation of the inability to reduce complex systems. In order to support Cilliers' contention that our brains adapt to experience therefore, we will begin by considering Freeman's model of the brain as a complex adaptive system. This supports much of Cilliers' argument with relation to adaptation from experience, but will also allow us to answer some of the critiques levelled at neural network models.

Freeman (1999) provides an account for the general audience of how the brain is constantly firing, according to 'chaotic'[44] electrical signals:

> "Chaos generates the disorder needed for creating new trials in trial-and-error learning...Its high-frequency oscillations maximize the likelihood of firing coincidences, which are required during the process of Hebbian learning" (Freeman, 1999, p. 90)

This firing is supported by some experimental evidence: Aihara (1995) found that giant squid axons displayed chaotic oscillation of membrane potentials suggesting that chaos plays a role in transferring impulses within neurons. Glass (1995) notes that the evidence for continual chaotic firing at the synaptic level is far from conclusive. Nevertheless, Freeman suggests that:

> "Chaotic dynamics may play a critical role in the Hebbian learning process, particularly in the construction of a new wing [new electrical pattern] that differs from any that have come before." (Freeman & Barrie, 1994, p. 30)

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[43] See www.humanbrainproject.eu

[44] Freeman uses the term 'chaotic dynamics' to talk about attractors and bifurcations (Freeman & Barrie, 1994) within electrical signals within the brain and as such this is commensurate with our use of the term 'complex' within this thesis.

In experimental work with rabbits (Skarda & Freeman, 1987; Freeman & Barrie, 2000) and monkeys (Freeman & van Dijk, 1987), the electrical activity across a region of the brain (what Freeman calls a "brain wave") is recorded by electroencephalographic (EEG) and models are used to recreate such waves (Freeman, 1987). By investigating the differences in these waves during the performing of tasks that the animals are trained for, versus in a rest state, Freeman models the brain as a self-organising system: electrical signals within the brain adapting in a complex way, with new EEG patterns emerging over time, indicating learning.

However, Freeman does not see learning as a simple response to stimuli: intentional behaviour plays a key role. Considering how the adaptation of electrical patterns is based upon their existing form, Freeman gives a detailed account of how "Intelligent behaviour is characterized by flexible and creative pursuit of endogeneously defined goals" (Freeman, 2000, p.1). These goals are emergent from the limbic system, which evolved in reptiles before forming a basis of the mammalian brain. Freeman describes how this part of the brain forms feedback loops which involve motor systems but also the priming of sensory systems to expect stimuli. Thus, Freeman explains, mammals continuously search for information in their environment by actions such as moving their gaze, and the limbic system continually generates neural activity which allows them to respond to the subsequent stimuli. The generation of 'readiness' in neural activity is known as *reafference* and Freeman describes how:

> "Everything that a human or an animal knows comes from this iterative process of action, reafference, perception, and up-date. It is done by successive frames that involve repeated state transitions and self-organized constructs in the sensory and limbic cortices." (Freeman, 2000, p. 4)

Freeman claims that such a model of learning "corresponds to Piaget's cycle of "action, assimilation, and adaptation" in the sensorimotor stage of childhood development." (Freeman, 2000, p. 4). Without exploring this link in detail, it serves to both relate such a neural model with existing learning theory but also highlight the limitation of such a model in relation to the later stages of Piaget's (1929) developmental theory, in which symbolic though and abstract representation become important. These cannot be explained by the limbic system alone. However, this brings into question Piaget's theory as much as it does Freeman's generalisation of limbic intentionality (as we shall see in Section 7.2).

Von der Malsberg (1995) develops a similar model of learning in the brain to Freeman[45]. He describes how fluctuations in electrical signals within the brain might propagate through neural networks and cause the weight of connections between neurons to increase. Through the feedback process of signals increasing as connection strength increases, the neural network is able to self-organise with high sensitivity to signals from sensory neurons.

Rather than focus on goal-orientated behaviour as Freeman does though, von der Malsberg discusses how there is genetic control of the interaction rules to favour useful connection patterns and that there is control by “central brain structures” in order to evaluate this usefulness. If a particular neural pattern is considered useful then a “gating signal” is sent out to all of the brain to authorise synaptic plasticity and in this way the brain selects the useful patterns from the multitude of emergent patterns that are stimulated continuously. Von der Malsberg’s model highlights “selective plasticity” within the brain: the existing structure of the brain has a role to play in determining the learning that takes place by controlling the neural populations which adapt. There are a number of ways at looking at this. Firstly by considering it as von der Malsberg does, as a “central brain” controlling what is learnt. Thus as a child develops they learn how to learn, by developing the capacity to choose what is important information and what is not. At a physiological level, the existing structure of the brain, having emerged from genetics and experience, conditions how it will continue to develop.

Selective plasticity also allows us to go some way towards addressing a further limitation of neural network models. Geake (2009) draws attention to non-Hebbian learning in which a single high-impact event is enough to induce learning without the need for repetition, and describes the evolutionary necessity of such learning as well as questioning whether it might be an important way to promote learning in the classroom. Although the mechanisms are far from clear, selective plasticity, along with our capacity to recall and relive key events, offers a partial explanation of learning from key events. Although we will not fully develop it within this thesis, a relation can also be proposed between selective plasticity at the physiological level and goal-oriented behaviour. Our goals may result in the selective plasticity of what we pay attention to and learn from. However, we must caution that in considering the limbic system primarily, Freeman is making a leap between the “primitive” goals of reptiles and the more sophisticated goals of what he calls “higher mammals”.

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[45] Von der Malsberg draws on Prigogine and Stengers’ (1984) general description of complexity, thus he specifically sets out to develop a complexity model.

Both Freeman and von der Malsberg develop models which go beyond the simple neural network model that Cilliers proposes. Brains are constantly processing signals from external stimuli but are also self-organising through complex dynamics of electrical signals. There appears to be adaptation at the level of populations of neurons which accounts for the adaptation of the brain to the world around. At a physiological level therefore, this provides a model of learning as complex adaptation to the environment, but mediated through existing neural structure at the time of that stimuli. This existing structure allows selective plasticity and may be related to goal-orientated behaviour.

We are thus developing an account of the brain as adaptive to the experiences a person has, but with their unique histories playing a role in how that adaptation takes place. This is allowing us to progress in developing an account of learning as a complex, yet material process.

4.1.4 Similar Brains, Different Learning

Whilst neuroscience supports a model of learning as the sophisticated adaptation to experience, this begs the question as to why we don't all have entirely different responses to the world. Chapter 5 is devoted to considering how we have shared understandings through interaction with other people and the material world. In relation to brain function however, we will here consider the role of genetics in determining similarities in our brain structure, and the role this plays in learning.

Our brains do not begin as entirely undifferentiated neural networks which then learn. The majority of contemporary neuroscience does not deal with individual neurons, or even neural systems, but instead focuses on specific areas or modules within the brain. What can be drawn from this focus on brain areas is that if the same brain areas correspond to certain behaviours in different humans (Hawrylycz, et al., 2012), then the structure of the brain must be determined by biological processes emanating from our genetics; the brain cannot be considered as a system that is fully plastic with respect to stimuli.

Cilliers (1998) recognises this and draws on Edelman (1987) and Changeaux (1984) in describing how the brain must have a *first repertoire* of structural organisation and a *second repertoire* of adaptation through experience. However this provides little by the way of explaining the processes involved. The interaction of genetics and experience as well as determining the level of plasticity in the brain presents significant experimental issues and conclusions are a long way off yet. Despite this, over the last couple of decades there have been tremendous advances in the ability to investigate the brain in action and a corresponding increase in models of this brain function which allow us to make tentative steps into further evaluating our neural model. In what are known as *large-scale brain network* models, specific areas of the brain are treated as nodes and their interaction investigated (Bressler & Menon, 2010; Bullmore & Sporns, 2009). What constitutes a node can be defined in a number of different ways according to a range of properties of the brain (e.g. nodes as areas with a specific biochemical makeup or neuron density) and this yields a range of different models. By greatly simplifying the internal processes of the nodes, the interactions between the nodes can be modelled in a similar way to the computational neural networks presented above. Whilst cautioning that the isolation of specific neural networks in this way is still an inaccurate representation of brain function Bressler & Menon argue that:

> "A new paradigm is emerging in cognitive neuroscience that moves beyond the simplistic mapping of cognitive constructs onto individual brain areas and emphasizes instead the conjoint function of brain areas working together as large-scale networks." (Bressler & Menon, 2010, p. 277)

There has already been promising work in identifying core functional brain networks (dealing with spatial attention, language, explicit memory, face-object recognition and working memory) and in relating these to disease and dementia. The electrical activity of brains across the whole organ develops through genetic evolution over long timescales but in the short term develops through self-organisation in response to stimuli and feedback loops which determine action.

The links between differences in micro-structure of brains and their activity is also gaining support (Pernice, et al., 2013). Of relevance to this thesis is that despite people having common neural structures at the macroscopic level, connections both within and between populations of networks within these structures allow for adaptation: for learning. This means the way we perceive the world and respond to certain stimuli will be conditioned by our evolutionary past. However, whilst having shared biology necessarily conditions our learning it still allows for infinite adaptation to experience. Contemporary neuroscience supports Freeman's model of adaptations across microscopic, mesoscopic and macroscopic levels of the brain, which differ in temporal and spatial scales. We thus arrive at a model of brain function that echoes the notion of distributed representation:

> "Mesoscopic brain states are not representations of stimuli, nor are they simple effects caused by stimuli. Each learned stimulus serves to elicit the construction of a

pattern that is shaped by synaptic modifications between cortical neurons from prior learning, which vastly outnumber the synapses formed by incoming sensory axons, and also by the brain stem nuclei that bathe the forebrain in neuromodulatory chemicals. Each cortical activity pattern is a dynamic operator that carries the meanings of stimuli for the recipient animal. It reflects the individual history, present context, and expectancy, corresponding to the unity and wholeness of intentionality. The patterns in each cortex are unique to each animal." (Freeman, 2000, p. 3)

Starting with Cillier's model of the brain as a neural network (4.1.1) we have evaluated the support from contemporary neuroscience and developed a more sophisticated model of how brains adapt to experience over time. Nevertheless this model supports the characterisation of understanding as distributed representations which develop as a material response to the world. To summarise, contemporary neuroscience supports a model of individual learning with the following tenants:

- Learning is not about simple representations of information within the brain but about patterns of neural activity which might be better described as distributed representation.
- The overall structure of the brain and the regions pertaining to different functions are determined genetically and are common to all humans.
- However, the specific patterns of neural activity which emerge from populations of synapses across the brain are unique to individuals.
- These patterns of activity determine the actions of individuals and also prepare the brain to sense the impact of those actions on the environment.
- In this way neural patterns are reinforced but there is also the possibility of new patterns emerging in what Freeman considers to be bifurcations of brain states. This is learning.

4.1.5 Learning as a Material Process

In this section we have developed a model of learning as the adaptation of neural structure and electrical patterns within the brain, mediated by human biology. It is worthwhile here expounding how this relates to the broader argument of this thesis: how such a model allows us to situate learning both as complex and as within a complex system. We are now in a position to provide specific mechanisms for Deleuze's claim that understanding emerges from experience (see Section 3.2). What is at stake is not the role of experience in learning, which is apparent. It is the development a material process that is of importance, in allowing us to situate learning within and as part of a complex system such as a classroom.

The model developed here suggests that the brain can be seen as a complex system which adapts in relation to experience, but also through 'internal' mechanisms[46]. However, this does not mean that experiences are encoded in a representational way, with neural networks or electrical patterns being structured as the outside world is. Cilliers' (1998) notion of distributed representation and Freeman's model of electrical adaptation can now be related to Deleuze's framing of experience as the genetic cause of understanding (see 3.2.7). Deleuze (2004a [1968]) developed a philosophical argument for how repeated exposure to 'different' but similar events leads to the development of understanding. Models of neural networks from Cilliers, Freeman and von der Malsberg show that the repeated exposure to similar situations leads to the adaptation of neural networks and the conditioning of responses to those situations. However, the history of the situation and specifics of the context mean that this is not simple conditioning[47]. By characterising the brain as a complex system we see that the minutiae of neural and electrical patterns may result in a nonlinear response to a stimulus such that there is significant change in brain structure, or there may be little impact at all.

We may provisionally follow Freeman (1999) and Edelman & Tononi (2000) in claiming that consciousness is emergent from brains, whilst recalling that this is not the same as consciousness being reducible to neural structure (see 3.1.2). Deleuze sees concepts as emergent from experience, as well as from the existing "image of thought". In the models we have considered across this section, understandings can be related to the structure of neurons and electrical signals in an individual's brain at any point. Whilst we will do more to account for shared understandings in Chapter 5, we have already provided a material account of concepts in terms of brains[48]. Learning is a material process by which our brains adapt to the rest of the world, but according to their existing structure.

By providing a material basis for Deleuze's metaphysics we are able to join post-structuralist thinkers in rejecting any fixed relationship between the world and our understandings, but without rejecting there being a relationship at all. Our understandings are emergent from the history of our brains and the specifics of the contexts they experience. In this section

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[46] Processes of reflection and consolidation, as well as forgetting are all processes which we might tentatively link to brain function, but which do not depend directly on stimuli at a particular moment.

[47] As behaviourist theorists may see it (e.g. Skinner, 1948)

[48] In subsection 7.2.3 we will develop further the relation between concepts and neural structure as we engage with contemporary issues in education, specifically literature on conceptual change.

therefore we have provided an account of brain function which both supports the materialist position developed in Chapter 3, but also furthers it for providing a specific account of how learning is material.

We are thus making headway with the problem this thesis sets out to tackle (defined in Section 1.3). By adapting Deleuze's materialist position we are able to provide a sound theoretical basis for bringing complexity theory to bear on learning. The difficulties faced by existing accounts of social complexity (see Chapter 2) stem from their failure to situate human understanding as part of the material world, and thus part of complex systems. If understanding is conceived of as relating to another realm of ideas, or as having a special position in relation to the material world, then it is not possible to maintain the complex interactions between experience and understanding. By providing a material basis for learning we are now able to account for how learners interact with the environment, and why their responses are themselves complex. Brains can be seen as complex entities which interact within complex systems.

However, in developing a specific model to support the materialist position posed in this thesis we are yet to account for two substantial areas. Firstly, we are yet to overcome Deleuze's reliance upon virtual causes to account for human creativity. The picture painted so far is of brains as complex systems which respond to stimuli, and that picture needs to be developed in order to gain a fuller appreciation of how context influences learning. Secondly, we are yet to account for how we have shared understandings. Both of these are relevant to developing a material account of learning within classrooms as complex systems. In Section 4.2 we will consider existing models of learning in context within the complexity literature. This will allow us to develop an account of learning within classrooms in Chapter 5.

4.2 Behaviour as Complex

4.2.1 Coordination Dynamics

We have so far developed a materialist model of learning as the adaptation of brains. Considering how such learning takes place within context will allow us to further this thesis in a number of ways. Firstly, it will allow us to consider learning within classrooms which will be developed in Chapter 5, by providing an account of how specific context influences learning. Secondly, we will draw upon a class of models associated with *coordination dynamics*, which offer greater potential utility to teachers and researchers than models of neural adaptation. Converse to the approach in the last section, these models begin with observed behaviour and describe it as a complex system. As such, hypotheses based on these models have the potential to be tested, critiqued and falsified in relation to empirical observation. Thirdly, in subsection 4.1.3 we will be in a position to overcome Deleuze's reliance upon the abstract notion of virtual causes (see 3.2.5) and instead provide a more concrete account of human agency within classrooms.

As a leading proponent of the coordination dynamics approach, Kelso describes how there are observable patterns across human behaviour[49]:

> "Much evidence suggests that the dynamic laws of neurobehavioural coordination are *sui generis*: they deal with collective properties that are repeatable from one system to another and emerge from microscopic dynamics but may not (even in principle) be deducible from them. Nevertheless, it is useful to try and understand the relationship between different levels while at the same time respecting the autonomy of each." (Kelso, et al., 2013, p. 120)

There is thus a tension in Kelso's work in that he is looking for dynamical patterns which are common across different scales within the brain, behaviour, and even in the coordination of two or more individuals. However Kelso is clear that our neural networks and behaviour are individual:

> "A general theory, then, is not (or not only) about the contents of mind and emotions and their neural correlates, which are unique to each of us. Rather it is about the dynamical processes of forming, breaking, uniting, dissolving, and harmonizing

[49] Stacey (2003a) thus uses Kelso's (1995) work to support his theory of complex responsive processes. However, the quote here shows that Kelso does not equate brain and behaviour as Stacey does, he merely claims there are common patterns of dynamics.

patterns of activity that occurs at all levels, and are common to all of us." (Kelso, et al., 2013, p. 129)

Kelso's contention therefore is that whilst we are each unique, there are physiological mechanisms for how we learn which can be seen in our behaviour and which correlate to dynamic patterns in the brain (but are not represented by them). In essence, the approach to investigating these mechanisms is to find some characteristic of behaviour which may be described by a mathematical parameter. For example, the rhythmic tapping of a finger might be related to the motion of a virtual finger on a computer screen and the relative dynamics of each described by equations which model their coordination. The frequencies at which the virtual and actual fingers go in and out of phase can then be investigated and this reveals *phase transitions*[50] and attractors within the dynamic equations.

In more sophisticated experiments, participants used customised joysticks and pressed buttons with their index fingers at increasing frequency, determined by a metronome (Kelso, 1984). It was found that above a certain critical frequency, participants are only able to press the buttons in phase (together) rather than out of phase (alternating fingers). However, it has been shown more recently that practice allows participants to increase the frequency at which they resort to pressing the buttons together, as they learn to maintain an out of phase pattern (Temprado, et al., 2002). This learning persists after seven days and thus such coordination becomes embedded in the nervous system in some way. This clearly shows that coordination is learnt through experience and we may take it as a first step in considering learning within context.

Such experiments show that human coordination can be described using nonlinear equations and that there are emergent phase transitions in coordinating movement in relation to stimuli. However, such mathematical descriptions are not limited to physical movement. 'Perception dynamics' is a field of interest within language learning. For example, when a range of sounds were played from a range between the word 'stay' and the word 'say' in a random order and participants had to decide which word was being played, it was found that there is a phase transition between the perception of these words (Case, et al., 1995). However, by changing the order in which the synthesised words were played, Case et al. found that people tended to stick to the word they had previously reported in ambiguous cases, a phenomenon known as *hysteresis*. More recent studies have built on this showing similar phase transitions (and

[50] A phase transition is a qualitative change. See Glossary.

hysteresis) in perceiving the difference between ‘bag’ and ‘back’ (Dahan, et al., 2008) and in the perception of ‘p’ and ‘b’ phonemes (Spivey, et al., 2009).

So coordination dynamics describes how patterns of behaviour will depend upon the history of the learners within the context they find themselves. The importance of context is further supported by the research of Thelen & Smith (1994), who model the development of young children as a dynamical system. They reason that:

> “Thought is embodied, that is, the structures used to put together our conceptual systems grow out of bodily experience and make sense in terms of it; moreover, the core of our conceptual systems is directly grounded in perception, body movement, and experience of a physical and social character.” (Thelen & Smith, 1994, p. 141)

By saying that “thought is embodied”, Thelen & Smith are supported by contemporary neuroscience which postulates that our brain functions are ‘multi-modal’, that is, the same systems are deployed for multiple purposes. Gallesse & Lakoff (2005) argue that the same neural systems are used for action as they are for imagined action. Thus the way we consider the world is conditioned by “simulation” of actions[51].

Drawing on such considerations, Thelen and her colleagues moved away from modelling development as symbolic reasoning and instead considered intelligence as being both made and realised through physical actions in the world (Smith, 2006). In this way, Thelen & Smith have investigated learning to crawl, walking and solving problems through observing the dynamics of limbs and eye movements (Thelen & Smith, 1994; Smith & Thelen, 2003; Beer, 2000). Thus, a developmental milestone such as crawling is seen as a self-organising solution to the problem of locomotion, before children have the strength and balance to walk. By investigating the patterns of limb movement as a child learns to crawl or stand up, and relating it to environmental influences such as the position of a toy or parent, this approach models the emergence of behaviour. Such studies draw on not only an appreciation of complex dynamics, but also a body of research into the mechanics of locomotion in animals such as horses (Hoyt & Taylor, 1981) and cockroaches (Full & Tu, 1991) which relates the configuration of limbs, body mass, forces and energy use to understand how animals change their mode of locomotion at different speeds. Although not explicitly related to dynamical equations, such research shows that the emergence of different solutions to the problem of movement can be seen as *embodied* in the physical characteristics of the animal.

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[51] See 7.2.3 for further discussion.

To further understand this approach when applied to learning, consider Smith & Thelen's (2003) investigation of an observation by Piaget (1963) that children between 8 and 10 months are not able to find a toy hidden in a new location, whereas by 12 months they are: the so called "A-not-B error". After being shown a toy being placed under cup A several times, the toy is then placed under cup B. Younger children still reach for cup A, even after having seen it go under cup B. Piaget postulated that this is because children below a critical age do not understand that objects can exist independently of their own actions. However, Smith & Thelen show that the outcomes of this task cannot be explained by cognitive development alone. They altered the time delay between hiding the toy and moving the cups forward, the ease of reaching each cup (using masses attached to each arm), the position that the child was in during the trial, and also whether the child was distracted, by indicating another nearby object between trials. They found that experimenters were able to produce the error in a range of different age children and indeed adults, but furthermore that an individual subject could be made to make the error or not according to the dynamics of particular factors in each trial.

The model developed by Smith & Thelen (2003) to explain the A-not-B error uses a "dynamic field" to represent a parameter that they called "activation". This is an approach common in physics which produces a multi-dimensional representation in which a range of influences are plotted against a dynamic parameter. In this case, activation is a result of the spatial properties of each trial, the times over which influences appear and functions representing memory of hiding the toy under cup A, as well as memory of a visual cue to cup B. Smith & Thelen (2003, p. 345) note that although inspired by a neural model, this field approach "is abstract and not anatomically specific." Here we see the use of a critical parameter to explain behaviour without a specific claim about its meaning; in this case, the parameter shows that a number of influences interact dynamically as a child reaches for a particular cup. There is no need to speculate about a single cause for this development or a separation of cognitive processing and action, instead the action can be seen as emergent from the dynamics of the situation at hand. This is important for consideration of learning within classrooms, as it highlights the sensitivity that a learner has to specific context.

Smith & Thelen explain how a dynamical systems approach allows us to transcend the tension between individual development and the global nature of development in which nearly all children eventually learn to solve problems such as the A-not-B error, learn to walk, speak their native language and form relationships. They note that shared biological heritage and similarities in environments allow for common development but nevertheless the socio-economic background or even being a sibling is not enough to determine outright development: there is considerable indeterminacy. Dynamical approaches thus provide a way of linking different timescales:

> "The coherence of time and levels of the complex system mean that dynamics of one time-scale (e.g. neural activity) must be continuous with and nested within the dynamics of all other timescales (e.g. growth, learning, and development)." (Smith & Thelen, 2003, p. 344)

As such, learning can be characterised not as the progression of common stages of development, as Piaget (1929) suggested, or as the processing of information in increasingly sophisticated representations (Bruner, 1966; 1978), but as the self-organisation of behaviour in response to the environment and biology.

Here though it could be contended that coordination dynamics deals with only developments which are determined by our biology, rather than by learning in social settings. We need a more sophisticated model to account for symbolic and social learning (see Chapter 5). Nevertheless, these studies provide us with evidence that it is not just our biology which determines when we learn: it is also the precise interaction of influences within the environment. As Beer suggests, this places cognition in a new light:

> "Although a dynamical approach can certainly stand alone, it is most powerful and distinctive when coupled with a situated, embodied perspective on cognition. From this perspective, the principle aim of a situated agent is to take action appropriate to its circumstances and goals, and cognition is merely one resource amongst many in service of this objective. Other important resources include the physical properties of an agent's body, the structure of its immediate environment (including artefacts such as shopping lists, calendars, computers, etc.) and its social context. In this sense, cognition can extend beyond an agent's brain to be distributed over a system of people and objects within an environment." (Beer, 2000, p. 97)

Neural network models of the brain propose that learning is the adaptation of neurons and electrical patterns. Coordination dynamics shows the role of the environment in developing new patterns of behaviour. Both provide models of learning as a process taking place within complex systems. We will now consider how these might be linked to form a more coherent picture of learning.

4.2.2 Linking Brain and Behaviour

Within the literature there is a clear implication that artificial connectionist models, dynamical models of behaviour and neuroscientific research are scratching at the same problem from different angles: how do brain and behaviour develop? As Beer comments above however, what would be most powerful is a model that links together brain and behaviour.

In aiming for such a link, Beer (2000) describes a robot that uses a simple neural network and seven rays of light to sense and respond to shape. The robot learns to move along a horizontal track in order to catch circular objects that fall from above, but not catch diamond shaped objects. As such, there is interplay of physical 'limbs', neural networks and the environment. Beer cautions that connectionist models and brain function need to be very carefully related to such dynamical systems. Nevertheless, the hope is that:

> "By supplying a common language for cognition, for the neurophysiological processes that support it, for non-cognitive behaviour, and for adaptive behaviour of simpler animals, a dynamical approach holds the promise of providing a unified theoretical framework for cognitive science, as well as an understanding of the emergence of cognition in development and evolution." (Beer, 2000, p. 97)

It is fair to say that there are still bridges to be built in order to link cognition, physiology and behaviour. However, attempts are being made to bring together these fields to develop a coherent model of learning. Of direct relevance to this thesis is the bridging of different approaches which all see learning as complex: emergent, dynamic and sensitive to context.

The recurrence of phase transitions in different models is seen by Spivey et al. (2009) as a phenomenon which provides a bridging point. They relate Freeman's models of phase transitions within neural EEG patterns to the bifurcation of behaviour seen within rhythmic movement, visual processing in optical illusions and interpretation of phonemes. They also go further in discussing the dynamics of "insight problem solving", and give the example of participants learning to predict the direction that a gear will move, when presented with a diagram of multiple gears. Participants in their study initially rehearse the direction of each gear in sequence, as displayed by their eye and hand movements. However, they soon realise that an even number of gears will result in the final gear moving in the opposite rotation to the drive gear and an odd number of gears will mean the opposite. What is particularly interesting is that in the trials before the realisation comes, records of hand and eye movement show increased "entropy": they move more quickly around the scene, and this could be used as a reliable predictor of a new mode of solving the problem.

Spivey et al. (2009) further relate this to studies in which participants are able to predict which triplet of words could be linked together and which could not. For example when presented with playing/credit/report and still/pages/music, the first triplet can be linked by the word 'card', but the second triplet has no linking word (Bowers, et al., 1990). In such tasks, participants are able to predict the right solution, even if they are not able to solve it. Bowden & Jung-Beeman (1998) use further studies to propose that there is a coarse processing of semantic information in the right hemisphere of the brain, which may recognise a solution before or even in the absence of the solution itself. Finer processing in the left hemisphere provides the solution, if there is one. Spivey et al, see the presence of phase transitions as a way of linking behaviour to dynamical systems.

In this thesis, the presence of phase transitions in learning supports the argument that learning is emergent, rather than being related to task or context in simple way. What is also noteworthy is that the cognitive processes being investigated could be classified as being symbolic or abstract in nature. There seems to be a link between physical coordination of hand and eye movements and the adaptation of conceptual understanding. This questions the separation of sensorimotor learning and abstract reasoning in existing learning (we will develop this argument in Chapter 7).

Whilst the nature of the links between cognition and sensorimotor action are far from clear, common characteristics such as phase transitions are seen as the nucleation points around which multiple perspectives may be brought together in explaining learning as a complex system:

> "In coordination dynamics, phase transitions are exploited both as a dynamical mechanism for effecting change ('switching', 'decision-making') and as a methodology to identify key collective variables and their dynamics. The reason is that in complex systems very many features can be measured but not all are relevant; coordination dynamics assumes that the variables that change qualitatively are the most important ones for system function (and, incidentally, for the scientist trying to understand it)." (Kelso, et al., 2013, p. 122)

Here we must remember that Kelso et al. recognise that each individual will have different brain patterns and different patterns of behaviour, but they are looking for the links between phase transitions at these two levels, as well as across different levels of brain analysis. What is promising is the capacity of this research to link cognition, brain and behaviour, as well as highlight the importance of context. The picture being painted is one of a nest of complex systems which interact and coevolve. Indeed, by adopting the materialist position developed in this thesis we can see this as a single system with interactions across various scales of heterogeneous elements.

However, there is also reason for caution in relation to these studies. Spivey et al. (2009) make reference to "underlying mechanisms" and we are reminded of our accounts in Section 2.1 of how scientists default to such reductionist terminology. Unlike, Spivey et al., Kelso and his collaborators are clearer about there not being an underlying mechanism to brain and behaviour, but rather there are multiple levels which can be linked together. Their error however is to see phase transitions and dynamic equations everywhere, describing language as a dynamical system (Rączaszek-Leonardi & Kelso, 2008) and also discussing "the complementary nature" of binary opposites (Engstrøm & Kelso, 2008). Incredibly, Kelso uses the application of coordination dynamics across a range of scales to argue that we should shift our understanding of all binary opposite:

> "In both coordination dynamics and the philosophy of complementary pairs, the squiggle character (~) signifies the symbolic punctuation of reconciled complementary pairs, as in whole~part, competition~cooperation, integration~segregation, time~space, and body~mind. The (~) character is neither trivial nor is it a fancy hyphen, but rather an indication of the complex, relational and complementary dynamics that exists between complementary aspects" (Engstrøm & Kelso, 2008, p. 123)

They believe that the equations of coordination dynamics can shed light on why humans tend to consider binary opposites. At best, this is a case of a scientist overstating the importance of his work and at worst it is the resurrection of Hegelian dialectics (see 2.2.6). Engstrøm & Kelso offer no criteria for a binary pair, nor any description of how coordination dynamics is relevant.

Work is still being undertaken on coordination dynamics and as results are published we must be cautious in evaluating the models and critiquing any assumptions about the universality of such dynamics. What has already been demonstrated is that models of both brain and behaviour can be devised which exhibit dynamical phase transitions, resulting from interactions of different components. Thus we are on safer ground if we propose that a phase transition in the brain may be linked to a phase transition in behaviour, although we cannot draw any simple conclusions about one causing the other. We do not yet know the balance between individual brain patterns and behaviour and shared biology underlying them, nor do we have a clear link between complexity at different levels, and this may be beyond our capacity.

However, it is possible to use the links between neural network models, models of brain function, cognitive neuroscience and coordination of behaviour to support the argument that learning and interaction can be characterised as complex processes, but within a materialist frame. The brain, cognition, behaviour and the environment can be seen as part of the same real world and indeed the same system.

4.2.3 Agency and Virtual Causes

In Section 4.2 we have presented models for learning being complex on a number of levels. By using the term 'complex' here we are drawing attention to features within the dynamic systems models described. Firstly, the reaction of an individual to a context will be historically contingent, both in terms of the neural structure of their brain, but also the hysteresis of their recent experience. Secondly, learning may be seen as 'nonlinear' in dynamic systems models: a child being able to solve the A-not-B problem or an adult being able to predict the motion of gears may happen suddenly, after a period of little change in their behaviour. Thirdly, we are able to support the contention that specific context is important in learning[52]. Whilst this may seem obvious, we will consider existing notions of curriculum and learning objectives in Chapter 7, and show that they overlook this insight.

However, the picture that has emerged from the models presented so far is one of human learning as the adaptation of complex systems on a range of scales. Recall from Section 2.3 that Byrne & Callaghan (2014) (drawing on Bhaskar (2008 [1975]), are concerned that human agency is removed within contemporary scientific models. Furthermore, recall that Deleuze's notion of virtual cause is partially[53] concerned with the unpredictability of human recall and response, as exemplified by cobble stones invoking a memory of Venice (see 3.2.5). As such we must consider how this thesis is characterising human agency.

The models presented in this chapter see the response of humans as emergent from the specifics of context, including the positioning of the body, and the neural and electrical structure of the brain. We have drawn attention also to continual processing within the brain of past events as well as present. Furthermore, Freeman's (2000) argument that thought and

[52] We might describe this as the system being open to the environment in complexity terms, or by seeing the context as part of the same system.
[53] As noted in 3.2.5, virtual causes also overturn the reliance upon a realm of 'possibilities'.

action cannot be easily separated (see 4.1.3) has been furthered by models of thought as embodied. Thus we have built a case for seeing the learning and response of humans as complex in the sense of being historically contingent, nonlinear, and sensitive to context. It is therefore only a small step to assert that this picture is able to account for the unpredictability of human response. The reason that cobble stones might inspire recall of Venice is because the neural networks within a person's brain are structured such that seeing cobble stones will evoke a response which was initially conditioned by experience of Venice, as well as the 'internal' processes of the brain in consolidating this experience. Such a response is historically contingent, nonlinear and context-specific.

Of course, this account is a very long way from a full description of the workings of the mind. The point here though is that human agency and the unpredictability of human response can be explained by the complexity of brains and bodies within contexts. As argued in 1.2.4, whether you subscribe to "strong emergence" or "weak emergence" (Osberg & Biesta, 2004), complex systems are unpredictable because they cannot be reduced. Therefore, it is not possible to predict what is important within the complex interactions of the brain, body and context. Human agency can be accounted for as the novel response of individuals based upon their histories (in the fullest sense) and the specifics of context. We do not need to distinguish between intensive and virtual causes to explain agency, as Deleuze does. In Deleuze's terms agency is the affirmation of our immanent experience (see 3.2.3), within a material multiplicity. We can account for the complexity of human response with intensive differences alone because the complexity of our brains interacting with the world allows for novel action.

This discussion takes us perilously close to philosophical debates around free will. However, we will only very tentatively situate the description of human agency developed here in relation to broader discussions around the mind. Within this thesis we have rejected dualist positions which separate mind and matter, primarily because in a complex system it is impossible to delineate between interacting aspects of any system, let alone alternative realms. This echoes Ryle's (2009 [1949], p. 5) argument against "the dogma of the Ghost in the Machine" in relation to dualist accounts of mind (particularly Descarte's). He too rejects the separation of mental and physical states. At the other extreme of the debate is the belief that consciousness can be reduced to physical matter, so-called "physicalism" (Pautz, 2010). The position developed in this thesis is different from physicalism in a subtle but important way. Whilst we are arguing for a materialist ontology in which mind should be seen as constituted by the material of brains, bodies and contexts, this does not mean that we can reduce it to these aspects. The insight from complexity is that a system cannot be reduced to its component parts and emergence cannot be fully predicted. This means that any attempt to explain human agency in terms of brain structure alone will significantly miss the point.

By accounting for the reliance upon history and the sensitivity to specific context, as well as internal brain processes, we recover human agency within a materialist frame. We have also overcome this aspect of virtual causes within Deleuze's system by providing models which support the unpredictability of human behaviour. However, human behaviour is not entirely unpredictable. Whilst we have considered how shared genetics mean that our brains develop in similar ways, this is not sufficient to account for shared understanding. This will be the subject of Chapter 5.

4.3 Chapter Conclusion

This chapter has provided specific models of learning which support learning being seen as both a material process and as complex, that is, emergent and context-specific.

In Chapter 3 we developed Deleuze's contention that humans learn from "multiplicities": repeated exposure to similar events. We also began the process of showing the advantage of a materialist position in not requiring mind to be seen as belonging to a different realm, or meaning to be constantly deferred. However, the account of learning remained philosophical in character and in need of specific mechanisms, which this chapter has provided. Drawing initially on Cilliers' (1998) models of artificial neural networks (subsection 4.1.1) and then relating this to contemporary neuroscientific understanding (4.1.2 to 4.1.5), we developed a model of learning as the adaptation of neural structure and electrical patterns. In Section 4.2 we then related this to observable behaviours and saw that learning is best considered as embodied. Coordinated action and cognition cannot be separated from processes in the brain. Whilst much work is still to be done to provide a comprehensive model of the interaction of brain, body and context in learning, we have shown that models of each of these can be coherently linked to support a materialist view. Learning is the co-adaptation of brains and bodies within the material world.

As well as supporting a materialist view of learning, the models presented in this chapter have highlighted the complexity of learning in two ways. Firstly by further supporting the realisation that asserting a material basis for learning is not the same as claiming it is reducible to that basis. Cilliers (1998) draws attention to the *distributed* nature of representation in artificial neural networks. There is not a clear relation between the world and neural structure. Freeman's (1999) work paints a picture of electrical patterns as unique to individuals, yet adapting to new experiences. Despite shared biology therefore every human has a different response to the world based upon their unique histories. That experience cannot be reconstructed by looking at brain structure.

This irreducibility is partially explained by the historic contingency of brains and bodies, which conditions their exact response, but we have also drawn attention to 'selective plasticity' which means that the way they develop is further conditioned by internal processes as well as response to new stimuli. As well as historic contingency, the second way in which the complexity of learning has been highlighted is in relation to context-specificity. Throughout Section 4.2 we saw a range of models in which the exact temporal and spatial aspects of how a problem is presented result in different outcomes. This is the case for coordinated movement of fingers (Kelso, 1984), perception of different words from ambiguous sounds (Case, et al., 1995), solving the A-not-B cup problem (Smith & Thelen, 2003), predicting the motion of gears (Spivey et al., 2009) and predicting links between words (Bowers, et al., 1990). We thus provided evidence that learning is not only dependent upon the history of the learner but on the specific context in which they are learning; learning is emergent from the material world. In this chapter therefore we have both supported the argument that learning should be characterised as a material (but irreducible) process, but have also shown how learning is complex in being emergent from specific context and dependent upon the unique history of learners.

The picture developed in this chapter is one of our understandings pertaining to the material world through a distributed representation of experience. Thus, learning is not the discovery of other-worldly truths but is the encoding of experience. Human action is therefore conditioned by past experience but also by the specifics of the context in which that action takes place. To be 'conditioned' by the past and by context however does not deny the presence of goals or 'internal' thought processes, it is simply to say that these goals and processes have an origin in both evolution and in a person's life history. Situating learning as a material process therefore does not deny agency or attempt to characterise it as mechanistic. In the last chapter we explained that a materialist position escapes the need for meaning to be constantly deferred and instead that meaning is defined in a specific moment (see 3.2.7). Having developed a more concrete account of learning we are now able to see that the full richness of a person's life experience is brought to bear on a particular moment, in a particular context. Humans have agency within complex systems: their responses are unique and emergent.

Having recovered human agency within a materialist frame therefore we beg the question as to why so many of our actions are actually predictable. How is it we have shared understandings of the world? How are we able to collaborate and communicate? It is to these issues that we will turn in Chapter 5.

5 Learning within Complex Classrooms

5.0 Chapter Introduction

In Chapter 4 we developed an account of learning as complex: historically contingent; nonlinear; sensitive to context. This was developed by taking Cilliers' (1998) model of neural networks and then considering neuroscientific models of learning and emergent behaviour. From this we learnt two things which will be important in accounting for social learning. Firstly, neural models support the contention that brains are conditioned by patterns of stimuli[54]. However, we also highlighted that brains do not just adapt to stimuli but also have 'internal' processes which mean that they are constantly processing and adapting. The second insight for considering social learning is the importance of context, both in terms of embodied learning and the agency of humans in specific contexts (see 4.2). Whilst we have thus provided a description of learning *in* context, what we also require is a description of learning *from* context.

Having already established that pupils respond to patterns of stimuli, further elucidating what we mean by patterns will account for how we come to have shared understandings. The job of this chapter is therefore to identify the patterns in the material world which influence us, and to characterise these within a materialist frame. To do so we will go through a number of stages. Firstly, Section 5.1 will establish how complex materialism allows an account of learning which does not rely on a categorical difference between learning in the natural world and learning in the social world. Drawing upon the models discussed in Chapter 4, we will see that the brain is able to respond to patterns and associations within heterogeneous elements of the classroom: images, speech, text, body language, music, equipment, etc. These all have a material basis and as such we are able to respond to, reproduce and manipulate the patterns we see in the classroom.

Having developed the notion of patterns we will then consider how we learn from each other (Section 5.2). We are able to learn by emulating others and coordinating our actions. In Chapter 4 we saw that learning is context-specific and this also holds for social interactions. Thus patterns of behaviour are reproduced but also evolve.

An advantage of seeing different aspects of the world as having a material basis is in being able to include learning from the classroom itself in an account of social learning (Section 5.3). This includes learning from objects, be they pieces of scientific equipment or a football in physical

[54] Adopting Freeman's (2000) description of goal-orientation we may go further and say that humans actively seek patterns (see 4.1.3).

education. However it also includes learning from the associations made to such items, for example the role of equipment in scientific experimentation or the rules of a game. Furthermore, we are able to include learning from symbolic systems as part of the material nature of learning, including learning from music, texts or mathematics. We are thus able to use the complex materialist position as a springboard for developing an account of how we learn from the behaviour of others, the associations of heterogeneous aspects of a classroom and the symbolic systems inherent in our culture.

As we cautioned at the beginning of Chapter 4, this thesis contains no primary empirical evidence. As such we will not develop a precise formulation of how pupils learn, again recalling that each case of learning is unique. This chapter will instead bring together a range of secondary evidence in order to show the plausibility and advantages of seeing classrooms, and pupils within them, as complex systems.

5.1 Learning from Patterns in the Material World

5.1.1 Learning from Patterns

It should already be clear that we wish to situate learning within a materialist frame, with shared understandings coming from interaction within the material world. This of course includes interaction with other people, but also the heterogeneous elements of the social sphere, and classrooms in particular: musical sounds, text on a page, images and audio-visual media, scientific equipment, etc. Recall the earlier quote from Beer (in 4.2.1):

> "cognition is merely one resource.. Other important resources include the physical properties of an agent's body, the structure of its immediate environment (including artefacts such as shopping lists, calendars, computers, etc.) and its social context. In this sense, cognition can extend beyond an agent's brain to be distributed over a system of people and objects within an environment." (Beer, 2000, p. 97)

Here Beer refers to 'artefacts' which form part of distributed systems of cognition. To consider the role of such artefacts in social learning, recall from Chapter 4 that humans respond to objects through neural patterns which have been condition by previous experience (as well as genetics). When we see an object it is the pattern of light which our brains responds to, when we hear, touch, smell or taste something it is the patterns of stimuli that our brains respond to[55].

However, there is no reason for us to focus upon objects. Manipulating a mathematical equation or writing a letter is to be seen as a practice embedded in the social world. Forms and structures should be considered as social artefacts: the fourteen-lines of a traditional sonnet, or the stages of a scientific investigation. Within the monist, materialist frame of this thesis these abstract forms can be seen to have a physical basis. We can therefore propose that such patterns influence the neural networks of learners: that we can learn from the abstract forms in the social world in the same way as we learn from objects and equipment. Here we are developing the notion that patterns exist across a range of scales, but our brains are capable of responding to these. Again, we encountered this in an earlier quote, when we were first developing the neural model of learning (see 4.1.2):

> "Clusters of information from the external world flow into the system… if a certain cluster is present regularly, the system will acquire stable weights that 'represent' that cluster, i.e. a certain pattern of activity will be caused in the system each time that

[55] Beyond the traditional five senses our brains also respond to a range of other influences: balance, motion, internal temperature, chemicals in the blood etc.

> specific cluster is present. If two clusters are regularly present together, the system will automatically develop an association between the two. For example, if a certain state of affairs regularly causes harm to the system, the system will associate that condition with harm without having to know before hand that the condition is harmful." (Cilliers, 1998, p. 93)

Here we see that 'clusters of information' take a variety of forms, with neural networks being able to associate 'a state of affairs' with 'harm'. The language being used is necessarily loose as it aims to capture the variety of possible stimuli that the brain can respond to, and form associations between. However, we will use the term *pattern* to denote objects, forms and clusters of information across all scales. The brain is able to respond to such patterns. Furthermore, we are not here restricting analysis to spatial patterns, but also referring to temporal patterns: patterns of behaviour. Artificial neural networks are capable of predicting motion as well as recognising images (see 4.1.1) and it is therefore reasonable to assume that our brains are able to recognise and respond to chains of events. Our experiences over varying timescales influence our understandings of the world.

Pupils learn from patterns within classrooms, both by watching others and by direct communication with other pupils, teachers, teaching assistants etc. By adopting a materialist position we are able to see that learning from the material world has the same character as social interactions, both in terms of experiencing the world of objects but also symbolic languages. Firstly, by adapting Deleuze's 'flat ontology' we are able to situate symbols and forms within the social world as being within the same ontological category as objects and people. Secondly, the model we developed in Chapter 4 proposes that learning is the recognition of patterns within the material world and the adaptation of responses to these patterns. Taken together we are able to assert that learning is the adaptation of brains to patterns, both within the natural and social world. We will develop these arguments throughout this chapter.

5.1.2 Patterns versus Objects

Asserting the importance of patterns begs the question as to whether we should see these patterns as autonomous entities in themselves. Recall Harman's objection to monism, considered briefly in subsection 3.1.1:

> "if the underworld is truly unformatted, then it is hard to see why it should suddenly be broken into parts by a human, who really ought to be just sleekly fused into the unformatted plasma as everything else." (Harman, 2011, p. 61)

Harman attacks Deleuze's[56] form of materialism which he calls "undermining" because reality is considered to be a single substance. He also dismisses "overmining" positions which claim that there are no characteristics implicit to objects and that they can only be defined by relations[57].

> "Overmining has become the central dogma of our time: everything is relations, or language, or appearance to the mind. This dogma cannot be countered with an undermining theory that views the world as a partless, rumbling depth. What is missing in both cases is the autonomous reality of individual objects: dogs, trees, flames, monuments, societies, ghosts, gods, pirates, coins, and rubies." (Harman, 2011, p. 71)

Deleuze's claim that the world is "heterogeneous" and "continuous" is particularly upsetting to Harman, as to him this becomes another form of dualism in which neither undermining nor overmining can account for the world of separate entities. The focus is simply shifted to another division of reality.

> "we have a heterogeneous-yet-continuous plane on one side and articulated entities on the other. Now as before, no room is left for form or structure *within* the realm of articulated actual entities" (Harman, 2011, p. 63)

We thus need to explain the seeming dualism in claiming the world has a singular substance and also asserting the importance of patterns in allowing human understanding. To develop this position we will here contrast it to Harman's proposal that we should consider objects as primary to understanding the world. In the next subsection, we will consider how focusing on patterns provides a more concrete account than Bourdieu's notion of 'social fields', which complex realists draw upon (see 2.3.2).

Harman's proposal is that we should consider objects as autonomous entities. However, the relations between our symbolic understandings and objects in the world are not accounted for in Harman's system. The insight from post-structuralist thinkers is that there is tension between fixed identities and the dynamic and nonlinear nature of the world (see Section 2.2).

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[56] Harman (2011) actually engages directly with DeLanda's interpretation of Deleuze. See 6.1.2.
[57] This overmining is characteristic of post-structuralist positions (see Section 2.2).

Take the view from semiotics[58] for example: if autonomous objects (the signified) have labels (signifiers), but these labels are not real, then we are returned to dualism. If these labels are themselves autonomous 'objects', then we are returned to a fixed and static world in which labels represent objects. The tension uncovered by post-structuralists becomes a full blown headache when we consider the relationships between mind and matter. Whilst perception is seen to relate to autonomous objects, we are not able to situate perception itself: are concepts to be seen as objects also? This is much the same issue that complex realists face in that understanding is not adequately situated as real (see Section 2.3).

As well as the issue in situating understanding, Harman's argument contains an implicit notion of scale: that undermining prioritises the sub-atomic and overmining prioritises a system of relations, and neither is able to account for the world of objects. However, his solution of autonomous objects suffers from the same problem of accounting for scale. Why is a legion just as real as a soldier, or a cell or an atom, and which is the autonomous object? These characterisations fail to see the capacity for emergence to link these scales. Deleuze proposes that the world is constituted by intensive differences, and we have suggested that this is commensurate with contemporary views from science (e.g. string theory). Yet emergence provides us with an account of how the dogs, trees and flames that Harman talks of can be constituted by the subatomic. There is nothing controversial in this claim.

An insight from complexity is that the world being constituted by the subatomic is not a bottom-up, reductionist account. Entities emerge which go on to have influence on differing temporal and spatial scales. What we have added to this insight is an account of how the world is "broken into parts by a human" (Harman, 2011, p. 61). Harman answers his own question in recognising that is humans who do the breaking apart. Cilliers (1998) uses the example of an artificial network learning to recognise trees, and we can assume that our brains at least have this capacity. Our evolutionary history means that we learn from our experiences and this includes identifying objects in the world. There is no need for claiming *a priori* the autonomy of those objects, as Harman wants to. Dogs, trees, flames, pirates, coins and rubies have a material basis but are not reducible to that basis; their identity is a facet of our perception, yet that perception is the response of brains to experience in the real world.

What of the societies, ghosts and gods that Harman mentions though, are these also real? These have a material basis in two senses: in the electrical patterns in the brains of people and

[58] Saussure separates signifiers and the signified and Derrida saw these as within a dynamic system. However, Deleuze argues that relations are context specific: relations do not have autonomous existence (Smith, 2009).

in social artefacts (music, words, images, mathematical symbols etc). In this sense ghosts are real without the need for them being autonomous entities: ghosts exist in the patterns of the social world[59]. We are thus arguing that patterns of behaviour and of communication through symbolic languages have a material basis. Patterns can include heterogeneous elements so our understanding of pirates is conditioned by cartoon pirates as much as the contemporary pirates in the news. Yet we respond to, reproduce and manipulate these patterns.

5.1.3 Patterns versus Fields

Here we will develop the notion of patterns further through contrasting it to accounts of human agency. Considering patterns in the material world allows us to see how we learn from heterogeneous elements of a classroom and from patterns across different scales of social systems. In this sense, to focus upon objects is too specific, as it considers just one aspect of reality and does not account for human understandings or the variety of what we can understand.

Conversely however, existing accounts of human agency within complex systems are not specific enough. So far within this thesis we have encountered several descriptions of human agency within the social world. Cilliers (1998) argues that meaning is deferred across a complex social network (see 2.2.5); Deleuze (2004b [1969]) considers an "image of thought" in which the experiences we have are related to the existing understandings in society (see 3.2.2); Byrne & Callaghan (2014) draw on Bourdieu's notion of "fields" which condition human agency (see 2.3.2). All of these are aimed at explaining how we have shared understandings and actions, yet also individual agency[60]. We will not enter into detailed comparison between these social theories and the position developed in this thesis. However, the intention here is to underline what is to be gained from characterising the patterns within classrooms as unique and context-specific.

To exemplify this we will consider how a materialist position provides a more concrete and tangible description of classrooms than Bourdieu's notion of "fields", as discussed by Byrne & Callaghan (2014, Chapter 5). The notion of social fields is used broadly in sociology (see Fligstein & McAdam, 2012) and Byrne & Callaghan use it to situate human agency within social

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[59] Here we begin to recover aspects of the social constructionist argument that social entities are developed by people. However, we have removed the untenable notion that the social and individual are the same, or the dialectic account of mind as privileged within the material world (see Section 2.4).

[60] There are of course other social theories which could be related to the arguments expressed in this thesis, for example, Latour's (2005) Actor Network Theory (further related to Deleuze by Blake (2004)) and Bandura's (1999) Social Cognitive Theory.

influences. Scientists use the term ‘field’ to define regions of space in which a force acts, and Bourdieu draws on this to describe social relations:

> “The field, as a field of possible forces, presents itself to each agent as a space of possibles which is defined in the relationship between the structure of average chances of access to the different positions… the objective probabilities (of economic or symbolic profit, for example) inscribed in the field at a given moment only become operative and active through “vocations”, “aspirations” and “expectations”, i.e. insofar as they are perceived and appreciated through the schemes of perception and appreciation which constitute a habitus.” Bourdieu (1983, p.344)

Bourdieu’s system involves *habitus* as the “vocations”, “aspirations” and “expectations” a person brings to a situation. However, whilst habitus conditions action, the potential for reflexivity allows self-awareness and agency in relation to one’s own habitus (Bourdieu & Wacquant, 1992). Habitus is also related to the *cultural capital* that a person (or object) has, which determines social status, and changes over time (Bourdieu, 1986). As such, Bourdieu sees thought and action as the continual struggle of people to achieve their goals within fields, but constrained by habitus and capital. Other ‘players’ on the field are engaged in their own struggle and the field is therefore constantly changing.

Byrne & Callaghan (2014) see synergy between complexity theory and Bourdieu’s account:

> “Both Bourdieu and Archer would subscribe to a social sphere as a not necessarily planned or even wished for outcome of processes of struggle which include conflict and negotiation between individuals and groups in conditions of differential levels of power. Both would see structure as having emergent properties whilst at the same time emergence is also evident, for Bourdieu particularly, in collective as well as individual action. In these respects both theories seem consistent with a flexible realist ontology.” (Byrne & Callaghan, 2014, p.124)

The question is how can an ontology be both “flexible” and “realist”? We argued that complex realists do not adequately situate their own understandings as within complex social systems (see 2.3.3). Here however we draw attention to the rather amorphous character of the term ‘fields’, which implies intangible forces conditioning human agency. In the above quote we see a constant struggle between individual and groups with different levels of power whereby emergence is ever present. We are left with only a general description of agency as within a broader social system. However, on closer inspection we see that fields are constituted by relations:

> "what exist in the social world are relations – not interactions between agents or intersubjective ties between individuals, but *objective relations*" (Bourdieu & Wacquant, 1992, p. 97)[61]

Bourdieu, Byrne and Callaghan are arguing for agency within a system of relations which is afforded an autonomous existence. This becomes a metaphysical issue in that we must ponder the nature of these intangible yet real relations, but it also becomes a practical issue in that any researcher must define relations in the classroom. Should we define a social relation in a brief glance, a conversation, a policy or written hierarchy, a family tree, by race or gender or species? As with Cilliers' system of relations, we quickly come to a world in which agency involves the processing of infinite possible relations within social fields (see 2.2.5). In the above quote we see that Bourdieu & Wacquant reject the subjectivity of relations, but we are offered no clues as to where we are to find objective relations.

A monist, materialist frame provides a solution by recognising that when people interact with the world and with each other, it is actually an interaction of matter. The relations we see in the world are encoded in our brains, as well as in the symbolic artefacts we have developed. This is not to return to a constructionist position in which relations are produced by us, it is instead a position which undermines the autonomy of relations beyond brains and symbols. For example, a relation between a teacher and pupil in conversation is the interaction of two embodied brains receiving and seeking stimuli from the senses. The relationship has a history which will have contributed to the exact neural structures at the moment of interaction, and it will have symbolic correlates such as the clothing, body language, position in the classroom, names on a register etc. These are all material though, and can be seen as the happenstance of matter in a particular moment. We do not need to develop a separate ontological category for relations.

Without entering into a full interrogation of Bourdieu's work, we can see that once we reject the autonomous existence of relations then the notions of field, habitus and capital can all be afforded a material basis. The patterns of behaviour, goals and expectations people bring to situations are encoded in their neural networks and will have developed through both their biological inheritance and their experience. Habitus and capital provide useful models for

[61] We earlier related this to network models (see 2.1.4)

exploring the patterns of behaviour and associations that people have, but we must recognise that each instance of these patterns is unique and has a material basis.

So what are relations? Whether we consider the relation between a label and an object, or between a teacher and a pupil, a materialist position proposes that we are seeing unique events. Once again, we must recall Deleuze's contention that concepts, in this case relations, come about through repeated exposure to similar circumstances. In this way the power relations between teacher and pupil manifest in the expectations that each have and the way they interact. So interaction between teacher and pupil develops over time. Relations do not need to be afforded an autonomous existence.

Deleuze's work therefore gives us a way of seeing that each instance of a pattern is unique, yet repeated exposure to such patterns comes to define relations between aspects of the world. We have built upon this suggestion by providing specific mechanisms for how we come to recognise patterns in the world through the adaptation of brain and behaviour (Chapter 4). The position developed in this thesis thus provides a more concrete account of how humans relate to each other than that provided by Bourdieu's social fields. We have resolved the tension between recognising that each instance is unique and how we come to recognise, repeat and manipulate patterns in the social world. In subsection 5.3.2 we will see that seeing patterns as unique but repeated allows us to provide a better description of how we learn from words and symbols than Cilliers' (1998) systems of distributed meaning. We might also suggest that we have gone beyond Deleuze's (2004b [1969]) own notion of an "image of thought". Relations, expectations and behaviours can be seen as repeated yet unique patterns.

In the rest of this chapter we will further expound how we learn from these repeated patterns. In this section we have considered how patterns need not be restricted to autonomous objects: they pertain to heterogeneous elements within classrooms. Conversely, we have seen how patterns provide a more tangible view of the social world than notions of social fields. We learn from the 'different yet repeated' patterns of the material world. In Section 5.2 we will flesh out this claim through discussion of existing evidence that pupils within a classroom learn from each other and from teachers. In Section 5.3 we will then consider how pupils learn from the social artefacts of the classroom: words, images, symbols, multimedia etc. This will allow us to build on this section in which we have laid out the theoretical premise of the argument. Recognising that learning is a process of our brains and behaviour adapting to our experiences (mediated by our biology) allows us to see that we learn from patterns within the material world.

5.2 Learning from Each Other

5.2.1 Empathy and Coordination

In this section we will explore evidence that pupils learn from others through emulating patterns of behaviour and coordinating their actions. This will demonstrate that it is possible to account for social aspects of learning within a materialist frame, but also highlight the importance of history and context in such learning.

Recall from Section 2.4 that Stacey develops a social constructionist account of learning through empathy. Drawing on Mead (1934), Stacey (2001, 2003a) claims that humans recognise actions in others and so assimilate these actions. Whilst we have shown Stacey's position to be untenable, the importance of empathy in learning is highlighted. This is not a new insight however. Experiments in the 1960s with 'Bobo dolls': inflatable toys which stay upright when struck, showed that after seeing an adult being aggressive towards the toy, children were more likely to act aggressively (Bandura, Ross & Ross, 1961). Similar influences were seen using video footage of aggressive behaviour (Bandura, Grusec & Menlove, 1966). This immediately suggests the capacity of children[62] to emulate observed behaviour without direct instruction. In this sense they are reproducing the patterns they see.

Other factors play a role in emulating, for example the reinforcement of patterns of behaviour with reward from parents or respected others. It is also possible to describe action rather than demonstrate it and thus we must consider the role of language in allowing patterns of behaviour to be reproduced (in older children at least). The capacity of people to recreate patterns of behaviour is important to this thesis and partially accounts for the existence of shared understandings, along with our common biology and capacity to learn from symbolic forms (which will be considered in Section 5.3).

Unconscious *mimicry* also plays a role in learning and social interaction; for example the spontaneous replication of body position when sitting next to somebody, or face touching whilst speaking to others. Van Baaren et. al. (2009) discuss the experimental evidence for social influences on this, for example:

> "when we are more concerned with others, dependent on them, feel closer to them, or want to be liked by them, we tend to take over their behaviour to a greater extent." (van Baaren, et al., 2009, p. 2382)

[62] The subjects were between 2 and 6 years old.

They also present evidence that mimicry is reduced when those interacting consider themselves to be from different social groups. Being mimicked is likely to enhance or reduce your appreciation for someone, dependent on whether you identify with them or not. Furthermore, there seems to be a temporal effect in that after being mimicked by someone they respected, subjects were likely to be more helpful to others.

Most teachers will be aware of non-verbal signals and the influence they have upon pupils: the way they position themselves in a room, the way they look at pupils, their body language. These patterns may be overt, as in the case of the Bobo dolls, or covert, as in the case of mimicry. Teachers both consciously and unconsciously use patterns of behaviour to influence learning. We need not see these patterns as anything other than material: enshrined in both our biological responses, and our learning within social settings, yet they influence behaviour in classrooms.

In support of the biological and material basis of patterns of behaviour, van Baaren et. al. tentatively propose a neurological process for mimicry, involving the *mirror systems* of the brain. His research group have undertaken a range of experiments looking at what happens in the brains of two people as they coordinate actions[63]. One such experiment was the analysis of EEG patterns when two people, sat opposite each other, moved their fingers rhythmically. A liquid crystal screen between the two was made alternately opaque or transparent. The researchers carefully tracked whether the fingers moved in phase and examined the neural correlates to coordinated and uncoordinated behaviour (Tognoli, 2008; Tognoli, et al., 2007; Tognoli & Kelso, 2015). In line with previous studies, they found that *alpha* waves (with a mean frequency of 10.61Hz) and *mu* waves (9.63Hz) responded to the sight of the other person. However, these were not directly correlated with coordinated behaviour. Instead, a component of the waves that they called *phi* (9.2-11.5Hz) was found to change according to whether the couple's finger motions were coordinated or not. In unsynchronised behaviour, there is an increase in phi waves within the right hemisphere of the brain and a decrease in the left hemisphere. During synchronised behaviour, the phi waves in the right hemisphere increase without a corresponding decrease in the left hemisphere.

Tognoli (2008) suggests that coordinated behaviours are probably adaptive, for example when two people learn to walk whilst carrying a load. He also suggests:

[63] This field extends the research into coordination dynamics that we explored in subsection 4.2.1, whereby key parameters are sought which describe patterns within brains, but also within coordinated behaviour.

> “Social integration is further engaged into high level social behaviour: overt adjustments has been suggested as a mechanism for social facilitation and empathy, covert adjustments (stimulation of the motor system by perceived action without associated production of a behaviour) for action understanding by direct matching of a conspecific’s motor behaviour into one’s motor system, and for skill learning.” (Tognoli, 2008, p. 12)

Neuroscience then, is able to provide hypotheses for particular aspects of human interaction and these may be of interest to educationalists. Here they show a biological basis for pupils learning from and responding to the actions of others. This is related to shared biology. For example, Dumas et. al (2012) simulated the brains of two individuals interacting and compared it to coupled brain scans of participants, who were able to see each other’s hand movement via video. They argue that:

> “the anatomical functional similarity across humans could explain a tendency to enter in synchronization while immersed in the same perceptual context or while doing the same perceptual-motor task.” (Dumas, et al., 2012, p. 9)

Thus, they tentatively propose that because our brains are anatomically similar, we are likely to enter into coupling of movements when we share environments. Although the modelling of precise mechanisms continues, what is striking is that there are clearly neurological correlates to social behaviour, and this supports a materialist picture in which learning cannot be separated from these neurological processes.

However, we should not see social interaction as deterministic either. Tognoli et al. (2007) found that 38% of their trials recorded no coordinated behaviour, 37% had only transient phase locking and therefore only 25% of the trials showed coordinated behaviour. Consideration of their methods shows that participants gave informed consent so we can speculate that they were conscious of their coordination and wilfully involved in coordination or otherwise. Indeed, Tognoli (2008) suggests that “social neglect” probably requires subjects to withdraw their attention from each other’s motion. As such the identification of possible mechanisms for coordination does not uncover deterministic rules of interaction.

This further highlights the role of intention in human behaviour. Gazzola, Rizzolatti, Wicker & Keysers (2007) detected differences in the level of activation of the neural mirror system, depending upon whether the observer understands the goals of the actions, and this shows that goals affect the neurological responses of individuals. It is not just goals that make classrooms difficult to relate to neuroscientific evidence however, both perspective and experience play a role. Jackson, Meltzoff & Decety (2006) found that observing actions from a first-person perspective is more tightly coupled to the sensory-motor system than from a third-person perspective, which requires observers to also process visuospatial information. However, they also suggest that:

> "the rote repetition of known movements is faster and more efficient (in terms of recruiting the relevant motor representation/motor program) from the 1st-person perspective, while the learning of new actions might be more robust and generalize further if seen from the 3rd-person perspective (which requires some transformation) because this would lend itself to a more effortful and better understanding of the spatial configuration of the action. The answer to the question of which perspective a teacher should take in modelling an action likely depends on the prior expertise of the student and the expected generalization and use of the learned response by the learner." (Jackson, Meltzoff & Decety, 2006, p. 437)

Although clearly an extrapolation from neuroscience to classrooms, suggestions of how teachers might model an action shows that the intentions of the teacher, experience of the student and location in the room all have bearing.

Furthermore there are temporal effects to social interaction. Oullier et al (2008) expand the work on coordinated finger movements to examine how the behaviour of each individual remains coordinated once they can no longer see each other. They found that participants would have related frequencies in just under a third of cases (31.3% ± 19.6) after they had seen each other's movements, as opposed to around one sixth of the time before (17.6%± 15.2). Interestingly, they also found differences in how participants changed their frequencies, depending upon whether they had the slower or faster frequency to begin with.

However, Oullier et al. note the experimental difficulties of investigating coordinated movement in larger groups in which interpersonal relationships become important. It is difficult to distinguish whether behaviour is coordinated or being led by an individual, or even an external factor, such as the synchronisation of clapping when music is played. Beek, Verchoor & Kelso warn:

> "that the sheer complexity of social psychological phenomena calls for a more reserved stance… Because dynamical social psychology is concerned with behavioural

> patterns occurring in different situations, it will have to identify the situational properties that constrain the resulting behaviour" (Beek, et al., 1997, p. 102)

They suggest that the way forward is still in looking for phase transitions in behaviour within social groups, but that this is only possible if we are able to account for differences in situations. However, it seems unlikely that it will ever be possible to identify such 'situational properties' in real social situations because they are multiple, subtle and complex.

Another area which needs further study is the exact role the mirror system plays. Whilst it appears to have a central role in many aspects of social interactions, Barsalsou hints that this begs further questions:

> "One central issue is assessing whether mirror systems do indeed play all these roles, and perhaps others. If so, then why do humans exhibit such different social abilities than nonhuman primates who also have mirror systems?" (Barsalou, 2008, p. 634)

Such questions fall well beyond current neuroscientific understanding, and the scope of this thesis. Experimental work into the coordination of brains shows that there are neurological mechanisms which have a bearing on how people interact. There is growing evidence that our interactions have a material basis, for example Apps, Lesage & Ramnani (2015) have shown that a specific area of the brain (the anterior cingulate cortex) responds to seeing other people make incorrect choices in a game, and suggest that this has relevance to teachers understanding what their pupils are thinking. However, such studies are a long way from investigating the real time development and activation of brains during a lesson.

Of direct relevance is the evidence that material processes influence social interaction. Only accounts of the mind as existing within the material world can explain the complex and nuanced influences on human behaviour and learning. Human interaction is highly sensitive to context and this supports the insight from complexity that it is nonlinear: small influences can have a big impact. These aspects of learning cannot be explained by seeing a fixed relationship between the world and our understanding of it. The brain has a complex response to its environment. However, there are patterns of interaction which are part of the social world: repeating aggressive behaviour, mimicking position or face touching, coordinated movement. These patterns have a material existence and influence learning. Whilst Mead's (1934) "calling forth in others" is the basis for social constructionist positions therefore, we are able to argue that such calling forth is based in the interaction of brains within the material world, and is context-specific. Human learning has a basis in brains, bodies and patterns of behaviour.

5.2.2 Learning in Groups

We concluded above that coordinated motion and study of mirror neurons is not yet advanced enough to be of direct use to educationalists. Indeed, reducing learning to such aspects does not capture the complexity of classroom learning.

However, educational theory has much to say already about social interactions. One area in which this is apparent is in group work. This ranges from pairs working on a worksheet to sophisticated "jigsaw tasks", where different group members complete aspects of the task before piecing the solution together (Slavin, 2010). There is a broad range of research into the influence of factors on learning in group tasks. For example, grouping pupils of different attainment levels gives different outcomes from grouping pupils with similar skill sets (Watson, 1992; Thurston et al., 2010). This suggests that the composition of groups makes a difference to the learning of the individuals within it. Different members of the group complete different aspects of a group task, and thus learn different things.

Teachers might use this to their advantage, presenting tasks which challenge different members of the group according to their needs. Of interest here though is that learning within groups can be seen as a dynamic process in which the composition of groups influences the learning of individuals. We might further relate this to insights around "transactive memory":

> "individual memory systems can become involved in larger, organized social memory systems that have emergent group mind properties not traceable to the individuals." (Wegner, Raymond & Erber, 1991)

Wegner, Raymond & Erber studied young adults in close couples and found that they were able to remember a list of objects better than pairs made up of strangers were. This supports the concept that people who are close develop a system of memory that is superior to that of individuals and newly formed groups. Wegner, Raymond & Erber were able to disrupt the transactive memory of the couples by enforcing a system for remembering. This implies that transactive memory develops unconsciously. Again, our focus here is to support the argument that social learning involves patterns of behaviour which emerge within the real world, and transactive memory links group learning to the distribution of information across individuals. We might tentatively propose that the group is 'learning' in a different way to the individuals within it. However we do not need to see such a distributed memory system as anything other than emergent from material interactions.

A host of other influences have been recognised in group work in classrooms. The collaborative skills that children have will determine how they perform on group tasks (Baines, Blatchford & Chowne, 2007). Furthermore, the way they talk to each other is important (Mercer, et al., 2004). As Sampson and Clark (2009) conclude, the outcomes of pupil interaction depend upon the task and the context. As such the pedagogical literature recognises the importance of 'group dynamics', a term often used by teachers. This supports a view of learning as resultant from the specific context of the learner, but highlights once again the importance of patterns of behaviour in social settings.

Beyond psychological and pedagogical literature lies a whole host of further considerations around interaction. Recall from 5.1.3 that Bourdieu (1986) refers to pupils' "cultural capital": the different experiences and parental expectations children bring to classrooms based on their socio-economic positions. We must also consider power relations, confidence, charisma, 'chemistry', attraction and any other factor which may influence interaction in groups, as well as consideration of how communication technology influences social interactions. So too must we realise the capacity of humans to process and reflect, and to be oriented by goals as well as whims. The point is not to provide an exhaustive list of influences on social interaction it is instead to highlight that interaction is context-specific, and historically contingent.

Yet we are also concerned with how these influences can be seen as material. In subsection 5.1.3 we described, in general terms, how relations are emergent from the histories of the parties involved and the specific contexts in which they find themselves. So relationships between people stem from both biology and experience; so too do expectations of behaviour. In this section we have provided specific examples of how this is the case.

We have seen that learning through empathy is possible through witnessing certain behaviour, even through video media (Bandura, Grusec & Menlove, 1966). Also, in simplistic, experimental setups coordinated behaviour has been found to have a basis in mirror neuron systems and correspond to specific frequencies of waves in the brain (Tognoli, 2008; Tognoli, et al., 2007; Tognoli & Kelso, 2015). This leads Dumas et al. (2012) to conclude that our shared biology is instrumental in allowing such interaction. However, work by van Baaren et. al. (2009) shows that emulating patterns of behaviour will depend upon the relationship between individuals and is influenced by prior interactions. We have also highlighted the sensitivity of these processes to context, in terms of the relationships between people; the capacity of the individuals in a group; the use of first-person or third-person perspectives; the temporal effects of someone being helpful previously. This sensitivity is further supported by pedagogical literature which highlights the range of influences on pupils working in groups. Evidence for transactive memory (Wegner, Raymond & Erber, 1991), as well as literature around different outcomes during group work suggests that learning in groups might be seen as the adaptation of the group as a whole, as well as individual brains, during group tasks. The learning of a pupil from other pupils or teachers within a classroom involves subtleties of coordination, body language, distributed information processing and emulating what we have seen others do.

Taken together, the variety of studies referred to in this section allow us to argue that learning from other people within a classroom is a material process, involving the reproduction of, response to and manipulation of patterns of behaviour. People learn from watching and interacting with each other, but this is not a simple process of “calling forth” as Mead would have it. Patterns of interaction are determined by our shared biology, but also by our unique histories and the specifics of the context at hand. Separating social interaction from the contexts in which it takes place and the specific histories of the individuals involved is not possible. This supports a view of learning from others as a complex yet material process.

5.3 Learning from the Classroom

5.3.1 Learning from the Material of the Classroom

People learn not just from direct social interactions, but also by engaging with books, music, images, buildings, technology and any other social artefact we might conceive of. In a materialist frame we are able to see that learning from the world of objects, learning from other people and learning from social artefacts does not warrant different metaphysical categories. Learning comes from experience in the material world. This is not a controversial claim; few would deny that engaging with a measuring cylinder in science, a ball in physical education or a keyboard in music allows us to learn within these school subjects. We have already provided an account of how we learn from experience, in Chapter 4. There we argued that learning is the adaptation of neural networks. Whilst the details of this model may be revised with new evidence, it does demonstrate that learning can be characterised as the response of an individual to the material world. This response is complex, yet nevertheless material.

We are thus able to account for the exploratory learning that takes place when a pupil is introduced to a new object, having never encountered it before, nor know its name or purpose. Such learning is learning from the objects themselves[64]. However, this type of learning is rare in classrooms: most learning involves instruction and interaction, as well as engagement with media and equipment. In Section 5.2 we argued that learning from other people fits within a materialist frame and involves biological mechanisms operating in specific contexts. We must now extend this to the reality of classrooms. People within classrooms do not just watch each other, or coordinate their movements, they interact with each other at the same time as interacting with social artefacts. So whilst learning the game of football involves experience of kicking a ball, it also involves interaction with other players, understanding the rules, engaging in tactics and strategy, and might even be associated with learning gender roles, regional allegiances and aspirations for future earnings. An experiment in science may involve genuinely novel findings but also learning the processes, historic context and social status of scientific endeavour. The point is that all of this is learnt together through experience.

In order to argue that learning is a complex yet material process therefore, we need to extend our account of learning from experience, and learning from other people, to include learning from the heterogeneous elements of classrooms: the words spoken, gestures and expressions

[64] Learning from computers and other interactive media stretches this definition, as we may encounter novel responses from programs, or encounter social interaction in diffuse ways.

of others; the images seen; the sounds heard; the objects and equipment. Deleuze's (2007) term "hodgepodge" is once again useful in capturing the diversity of elements within classrooms. We should also reiterate that we cannot give a specific account of how learning takes place in a classroom for two reasons: firstly because this is a theoretical study involving no primary empirical evidence, and secondly because we have already built a case for the importance of context, history and emergence in learning, making each instance unique. However, the aim here is to show that considering the hodgepodge of elements within a classroom as having a material basis allows us to understand how all of these contribute to the complexity of learning.

We have proposed above that learning involves the reproduction of, response to and manipulation of patterns. So far we have considered this in relation to witnessing the behaviour of other people and to the behaviour of objects. As pupils learn they experience the patterns of association between aspects of a subject. So in football, the ball, the utterances on the pitch and the aggressive behaviour become associated as patterns of heterogeneous elements. Pupils then set about replicating those patterns. In science we might see copper metal burn with a blue-green flame but associate this with the abstract notion of the periodic table, wearing white coats, and fireworks. Learning is about developing patterns and links between diverse elements of experience. When a pupil is asked how a firework gives a blue-green explosion, they may recall the word copper and a range of associated notions.

The picture emerging is one of our brains being able to recognise patterns within classrooms. We have considered patterns on a number of levels: in emulating patterns of behaviour and mimicry, in coordinated behaviour and transactive memory, and from the behaviour of equipment in the classroom. However, by adopting the theoretical position developed in this thesis we are able to see that patterns of association between heterogeneous elements also leads to the adaptation of neural networks. We learn from all aspects of the natural and social world and characterising this all as material allows us to see how words, numbers, musical notes and images all contribute to the adaptation of understandings, without invoking a separate realm of mind.

There are a range of points to clarify following this theoretical description of classroom learning. Firstly, that we are advocating a distributed representation of the material world on two levels. An individual brain has a distributed representation of an association such as between copper and fireworks; there is not a neural pattern which corresponds directly to this understanding. Furthermore, the fact that copper and fireworks are linked is not an 'external' truth that predates the invention of fireworks: it is an association which evolved in human history and is now encoded in numerous different forms in different brains, and in books and other media. Everybody who knows about the association will have slightly different interpretations, but the pattern nevertheless allows a shared understanding. We shall return to this in subsection 5.3.3.

The second point of clarification is that in explaining how we associate heterogeneous elements of a classroom, we are not advocating the kind of operant conditioning that behaviourist theorists identified (e.g. Skinner, 1948). Pupils will approach new experiences with the neural networks they already have, developed from prior experience. So new experiences allow the adaptation of neural networks but based on their existing form. Pupils are not conditioned by their experiences alone but their histories and context play a role. On the cognitive level, motivation and reward are important in conditioning response[65]. We also have the capacity to reflect: processing information over time and linking it to other experiences. Both in this chapter and the last, we have stressed the importance of context in learning and the unique response that every learner will have.

We are therefore arguing that each person has an individual interpretation based on their unique experience, yet there are patterns within the social world which lead to shared understandings. We can all recognise a pigeon and discuss pigeons without each having the same experience of pigeons. Whilst this is obvious for 'objects' such a pigeons, we have developed a theoretical position which allows us to propose that this is also the case for more amorphous patterns. The behaviour of objects, animals and people may be seen as patterns but so too the association of heterogeneous aspects of the world, copper and blue-green fireworks for example.

The third point of clarification is around the role of words and other abstract symbols (mathematics, logos, road signs etc.). What most clearly sets human learning apart from most other animals is our use of a sophisticated symbolic language. We learn from patterns of symbols in the same way as we learn from the natural world. Recognising a pear tree and recognising a word, or number, or musical note do not need to be conceived of as different processes: each is the response to patterns of stimuli in the world. In this way, humans are able to have shared yet unique understandings of the natural, social and symbolic world.

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[65] Recall von der Malsberg's (1995) suggestion that selective plasticity provides a mechanism for 'higher brain function' of this type. See subsection 4.1.3

To illustrate this, consider this thesis. The specific combination of words is unique and yet the same words can be found across the world, and the overall form of the thesis has been produced many times. The letters on this page have a material basis in the ink they are printed with and the pattern of light incident on the reader's eye. The receptive organs of the eyes and overall brain structure of readers will also be similar, due to our shared biology. The patterns of each word and their approximate meaning will be shared, allowing discussion of the thesis. Yet the precise response of every reader will be different, based upon their unique histories and context. The thesis has a material reality, and yet is a social artefact which supports both shared understanding and individual interpretations.

In subsection 3.2.2 we outlined Deleuze's (2004a [1968]) notion of identity stemming from the "difference and repetition" of experience. Through Chapter 4 we developed a concrete mechanism for this involving the adaptation of neural networks in the brain. In this chapter so far, we have taken this further and outlined how treating every aspect of a classroom as having a material basis allows us to see how we learn from, reproduce and manipulate patterns within the material world.

5.3.2 Learning from Words and Symbols

Having outlined how we should see patterns as 'different but repeated', we will now more carefully develop the argument that seeing these patterns as material allows us to account for shared understandings. To build this argument we will firstly consider how a symbol such as a word can be seen to have a material existence yet influence and encode the response of people in a classroom. From this we will then consider how more nuanced patterns of heterogeneous elements can be seen as material, and allow shared understanding.

In a classroom a word has a material basis as ink on a page, pixels on a screen or in sounds: vibrations of air. Cilliers (1998, 2005a), drawing on Derrida, argues that meaning can only be resolved within a network, so a word can only be given meaning by relating it to all other words[66] (see 2.2.3). Whilst Cilliers argues for the boundaries of context making meaning intelligible in practice we pointed to the difficulty of this constant deferral, and the implication that a person interrogates relations and boundaries in real time (see 2.2.5).

We have already seen that to Deleuze meaning is in the moment (see 3.2.7). Making this more concrete we can argue that the response of members of the class to a word will be a product of the exact context and the (embodied) response of their brains, based upon their biology and

[66] Derrida more broadly sees a system of signifiers and signified (see Section 2.2).

previous experiences. The context will include the other words in a sentence, paragraph or discussion, the exact tone, the body language and relationships of those involved, the understanding of roles (e.g. teacher, student) that people have. These influences, and many others, have a material basis in the specifics of the moment. We do not process the material context in an exhaustive way, we simply respond to the patterns of stimuli. Thus whilst we might discuss the relationship between two people, in a particular moment this is manifest in the response of one person to another, more fundamentally the pattern of light and sound from that person. So too will expectation of roles be emergent from the brain patterns and details of the moment. Relationships and expectations have a material basis, although we don't deal with them on this level.

Furthermore, an incidence of a particular word in a particular context is not just something people respond to, they also learn from it. The way that the word is spelt, pronounced and used is also part of the learning: part of the experience which will lead to neural adaptation. From hearing or seeing a word used it is possible for a learner to begin to understand its pattern of usage. Repeated use and exposure to the contexts in which it is used allows more nuanced understandings. The learner may then go on to use the word themselves, thus reproducing the sound or pattern of ink. The insight of post-structuralist thinkers such as Derrida is that our linguistic systems do not have access to a realm of truth (see section 2.2). We have recovered this insight without the need for a troubled metaphysics or constant deferral of meaning. It is not just the post-structuralist tradition that has cast doubt on language being directly representative of the world however:

> "For a large class of cases of the employment of the word 'meaning'—though not for all—this way can be explained in this way: the meaning of a word is its use in the language" Wittgenstein (2009 [1953], p. 43)

Characterising words and linguistic forms as having a complex correspondence with the world allows us to see language as a complex system itself (Rączaszek-Leonardi & Kelso, 2008). However, by adopting a Deleuzian frame we are able to see symbols, words and linguistic forms as material. As such, language can be seen to evolve as part of the material world, with people recognising, reproducing and adapting symbolic forms.

Without fully entering into debates around language, the position being proposed here is that the pattern of a particular word comes to be recognised in relation to the contexts in which it is experienced. We have proposed that this is because these contexts result in adaptation of brain structures.

So how should we characterise these patterns: words? Firstly, we do not need to afford them an autonomous existence beyond specific contexts. If all written instances and recordings of a word disappeared, and people who recall the word died, the word would cease to exist. On the ‘human level’ we engage with words as distinct entities but Deleuze’s insight is that every instance of a word is different. They do not pertain to an Ideal realm as Plato’s metaphysics suggests, to a self-realising Spirit as Hegel has it, or to fundamental categories as Kant describes. Words are constituted by the “difference and repetition” that Deleuze (2004a [1968]) talks of.

Words are not learned and (re)used by people in exactly the same context each time, but in contexts which are sufficiently similar to stimulate a response in the brain. This characterisation of words has a synergy with complexity, as we see the persistence of forms but the potential for change. For example, Larsen-Freeman (2012) draws on complexity theory in relation to language learning to propose that:

> “we should not think of repetition as exact replication, but rather we should think of it as iteration that generates variation. Thus, what results from iteration is a mutable state. Iteration is one way that we create options in how to make meaning, position ourselves in the world as we want, understand the differences which we encounter in others, and adapt to a changing context.” (Larsen-Freeman, 2012, p. 1)

Each instance of a word is unique and has a unique context; equally, every brain that experiences a pattern has a unique history and neural structure at that moment. Considering this, it is not surprising that new and novel interpretations, links and responses emerge. Thus we might see human agency as the potential for emergence stemming from specific context and the specific histories of people present. However, this is not to deny the potential for conscious manipulation of words. In speech we can deliberately modify tone, volume, accent and written words can be given different styles, sizes, colours etc.

To be clear about the argument so far, we are proposing that each instance of a word is unique and has a material basis. The patterns of such words are recognised by humans because of their previous exposure to those patterns. Words are repeated in similar but different contexts and as such the patterns of those words persist over time. Shared understanding of words is therefore emergent from the use of reproduced patterns of those words. The response of each person to a word will depend upon the exact context and their embodied neural structure at that specific moment.

However, we should not see 'response' as a mechanistic output based on stimulus. The response of an individual to a spoken word is related to their focus upon the speaker, relationship with that person, goals within the moment, understanding of roles, preconceptions about the situation and a myriad other considerations. The 'response' of the listener is emergent from the material of the specific context and their embodied brains at that moment[67]. Thus we are able to provide a material basis for human agency without diminishing the potential for novelty in any situation.

Of course, word use does not constitute all of classroom practice. The above was intended to provide an initial account of how words, as symbolic forms, have a material basis and a material influence: how they allow shared understandings yet allow novelty. We must now expand this to consider less tangible patterns of behaviour and association.

Whilst we have so far considered words, patterns of language might be best considered on the level of whole phrases, discussions or written texts. Words are combined in a way that reflects the understandings and goals of the people involved and this provides a much larger scope for novelty and manipulation than using individual words. We are here expanding our focus from a system of words, with their place in a sentence being considered as part of the context, to a focus on the broader system of language use. We should be clear that we are therefore defining a different complex system, one which incorporates the use of words but also recognises the emergent influence of whole sentences, phrases, discussions etc. In Chapter 6 we will further elucidate how different models, of different 'levels' of a classroom, should be related. Here it is important to show that emergence allows us to link different scales of analysis whilst recognising that this does not mean we can reduce one to another. Whilst sentences are made of words, and therefore have a material basis, the influence of a sentence should not be seen as the aggregate of the influence of each word. This is demonstrable by the use of the same word in sentences of very different meaning, and furthermore by words such as 'material' which have different meaning in different contexts.

Patterns of word use: sentence structure and grammar, phrases, colloquialisms, all have a basis in the specific contexts in which they are used. Again, the proposal is that these patterns need not be given an autonomous existence. They are learned, repeated and adapted by

[67] See 8.3.2 for a broader critique of how 'response' is used within this thesis.

people within specific contexts. In a classroom, a phrase such as "I am giving you a C1" may have significance, relating to the first 'caution' in a disciplinary system. Both teachers and pupils learn the usage and influence of such a phrase as it is repeated, and its usage is adapted to new situations. Nevertheless it has a material existence in those specific situations, in written documentation and in the brains of people in the school. We thus see that whilst phrases are less easily identified than specific words, they have a material basis and are learned, reproduced and manipulated in classrooms.

It is easy to see that the analysis of words and phrases as material can be applied to mathematical symbols also. Arguably, mathematical symbols have more specific rules for usage than words and we may thus see mathematics as a system with different dynamics to that of language. Mathematical symbols have a correspondence to the material world in describing it, but it is also apparent that, like language, mathematics 'has a life of its own': mathematical forms can be developed with very little correspondence to the broader world. Nevertheless, mathematics is manifest in the symbols which exist as patterns of ink, in computers and scratched on rocks, as well as in the brains of people who understand it. New mathematical expressions are developed in relation to new contexts and this often involves the development of new symbols and terms. Whilst far from a full account of mathematics, this highlights that symbolic systems of all types can be seen as having a material reality yet influence learning and action.

5.3.3 Learning from Patterns

In Section 5.2 we considered how behaviour might be learned from others, as well as from videos and media. In this section so far we have considered how words and symbols are reproduced and manipulated within systems such as classrooms, and how they influence us. This has all been framed within the materialist position developed within this thesis. We are now in the position to see how associations may be formed between behaviours, words, images and any other aspect of a classroom, and how these associations are reproduced.

Recall the example of an association being made between the element copper and blue-green fireworks (subsection 5.3.1). Complex materialism sees the heterogeneous aspects of a classroom as having a material influence on brains and bodies. So the word 'firework', an image of a blue-green plume in the night sky, a piece of copper and being in a science lesson might become associated in the electrical patterns of a pupil's brain. This association could be reinforced by repeated exposure to these elements together, in presentation from a teacher, videos, activities which ask pupils to select from elements and colours, revision and homework. The point is that our brains are able to process these diverse elements, because what is actually being processed is a pattern of stimuli from the senses.

As noted before, this is much more sophisticated than operant conditioning though. Firstly, learning builds on existing associations. So a pupil presented with the word ‘copper’, a piece of copper, the symbol Cu, or an image of copper filings, would all contribute to the association of copper with blue-green fireworks[68]. This capacity for learning to accumulate is further highlighted when we recognise that older pupils are able to form associations just by being told something. All literature is based on this very capacity to bring together new associations with nothing more than words. The second distinction to be made between the picture of learning in this thesis and simple conditioning is that motivation, relationships, expectations, rewards and sanctions will all play a role. These will condition the learning and reproduction of patterns of behaviour: object/equipment use, word use and associations. The reward of a gesture, being given a sticker or hearing “well done” may have a significant influence on consolidation of that particular behaviour and future goals in relation to it.

Whilst the example of copper and fireworks is related to ‘curriculum content’[69], we might equally consider the form of an activity. Take the much overused practice of a ‘true or false’ quiz at the end of a lesson. Pupils learn the patterns of such events: that when they see sentences on the board with “true/false” next to them they need to select one of these options. The response of a pupil to such an activity is a material response of their brains and bodies, within the specific context. The repeated form of the activity is familiar despite it being applied to different subject matter, in a different time and place. The pattern is ‘repeated but different’ and the response is unique to the circumstances.

In recognising that our brains are dealing with heterogeneous patterns within the hodgepodge of classrooms we quickly lose the capacity to talk about easily definable patterns such as gestures, words and symbols. So too do we soon exceed the capacity for simple experiments to support our arguments. Our theoretical position explains why this is the case. Each instance of a pattern, of an association between heterogonous elements, is unique, and we can only ever give a very general description of brain patterns or patterns in the broader world. In Chapters 6 and 7 we will consider the implications of this for researchers and for teachers. The argument of this chapter however is that complex materialism provides a theoretical basis for seeing how pupils come to learn from patterns within the material of

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[68] Whilst a mechanism for this lies way beyond the scope of this thesis, recall that Freeman (1999) suggests that new brain activity must be based on existing electrical patterns.

[69] See Section 7.3 for a discussion of the epistemology of curricula in light of complex materialism.

classrooms. Shared understandings come from the behaviour of objects and people, but also the patterns of association between words, equations, actions, images, sounds and any other elements of the classroom. Our brains respond to specific instances of these patterns and reproduce them, but this is not to deny continual novelty within a complex and dynamic system. Characterising our brains as material systems which are continually processing and reprocessing stimuli allows us to see how we are part of the material world and so too are the patterns which allow our shared understandings.

5.4 Chapter Conclusion

Here we will bring together the arguments across the last three chapters by summarising the position of complex materialism which has been developed, before considering the implications for researchers and teachers in Chapters 6 and 7 respectively.

The problem posed by Chapters 1 and 2 was that of situating our understandings within a complex system such as a classroom. Existing theoretical positions all have deficiencies in relating human understanding to the rest of the material world. Learning, which we initially defined only as the development of understanding, is either characterised as a simple mechanistic process or neglected altogether by scientific accounts (Section 2.1). Post-structuralist thinkers (Section 2.2) see learning as complex and dynamic, and refute a simple relationship between the world and our understandings. However, this becomes a limiting frame in which very little can be said beyond the difficulties of defining meaning. In reaction to this, complex realists (Section 2.3) assert the importance of empirical evidence, but in so doing revert back to situating our understandings as somehow outside of the social systems they seek to investigate. This is taken to extremes by social constructionists (Section 2.4), who favour mind and social understandings to the point that they neglect the real world altogether. From these issues we distilled the need for a theoretical position that accounts for the role that the real world plays in learning, that situates learning in relation to this real world and that is able to explain the relationship between our models of classrooms and the classrooms themselves. Complex materialism is able to answer these requirements.

In Chapter 3 we outlined a materialist position adapted from Deleuze. This provided us with a way of seeing how our understandings could be situated within a complex social system, by recognising that our understandings are material and emerge from our experiences within a material world. In a complex system, where nonlinear and dynamic interaction is taking place between our understandings and the broader world, it is untenable to situate our minds or ideas in some supernatural realm which only humans have access to. Only by situating learning as a material process within a material world can you see how ideas and experience are related.

As well as allowing us to see how understandings and experience are related, the materialist frame allows us to further escape the need for an inexhaustible system of relations in order to define meaning in a complex system. Deleuze's position exposes the difficulty of seeing meaning as externally defined, beyond the specifics of each moment. Whilst providing an advantageous position for considering learning within complex systems, our interpretation of

Deleuze alone was not sufficient to account for how learning emerges from experience. The job of Chapter 4 was therefore to provide a specific process to support this.

Drawing initially upon Cilliers' model of neural networks, we showed how brains might be considered as pattern-processing machines. Our neural structures and associated electrical activity adapts to the world around it, through the development of the body (nature) and the experiences within a person's life (nurture). By relating this initial model to a range of evidence from neurological studies, behavioural studies and cognitive science we developed a plausible account of how learning is the adaptation of brains and bodies within the specific contexts people experience. This provided support for the materialist position, but also highlighted insights from complexity. Firstly, that although learning is a material process in a material world, this does not mean that it can be reduced to material correlates. Our understandings have a correlation to the material world in which they are formed but there is not a simple correspondence; they do not represent the real world 'as it is'. Our understandings are complex and dynamic and so is the broader world in which they develop. Seeing learning as complex highlights its sensitivity to the specific context in which it takes place and also to the histories of pupils as they learn. From this potential for novelty we began to recover a notion of human agency.

However, accounting for the potential novelty of human learning and action in relation to the broader world begs the question as to how we come to have shared understandings. This is a vital question in understanding education: how we learn what is already known by others. Chapter 5, this chapter, provides a broader view of learning from a material world in which there are shared understandings. We explored how these understandings can be explained by patterns within the social world: patterns of behaviour, patterns of symbolic forms such as language and mathematics, but also patterns of associations between heterogeneous aspects of classrooms. We learn from, reproduce and manipulate (both consciously and unconsciously) the patterns within the social world. In drawing together Chapters 4 and 5 we can see that the specific contexts in which we learn, and specific histories we bring to those contexts, provides constant potential for novelty. This includes the distribution of tasks amongst members of a group, the relationships, goals, motivations, schemas and expectations of the people in classrooms.

Yet we have shared understandings because patterns of behaviour and associations are reproduced, albeit inexactly. Within the complex materialist frame we again stressed our inability to reduce the social world to these patterns and expounded this further by underlining Deleuze's insight that each instance of a pattern is unique. We need not afford patterns a supernatural or autonomous status. Whilst the social world is complex and irreducible it is nevertheless material.

In defining complex materialism across Chapters 3, 4 and 5 we have therefore met two of the three criteria we set ourselves for a theoretical position equal to classroom learning. We have situated learning as a material process within a material world. In so doing we have characterised our understandings as having a complex and dynamic relation to the broader world. However, in relation to the third criteria we are yet to fully expound how our models of classrooms should be characterised. This is the basis of Chapter 6.

6 Implications: Understanding Classrooms

6.0 Chapter Introduction

At the end of Chapter 2 we argued that in order to meet the challenge of social complexity, a theoretical position must do three things: it must be able to account for the role that the real world plays in developing our understandings; it must situate our understandings relative to this real world; it must account for how our models and understandings are themselves within complex social systems. So far we have situated learning as a material process within complex classrooms and this has allowed us to answer the first two challenges. We now turn to the challenge of situating our models of classroom learning, relative to classrooms themselves.

As touched upon in 3.1.3, the solution will come from recognising our models as themselves specific and material, and therefore able to influence the broader world. To establish this argument we will first of all show how models should be considered as material entities (subsection 6.1.1). However, characterising models as material alone does not explain how models relate to what they model. By critiquing DeLanda's account of models sharing 'virtual attractors', we will show how this thesis provides a better solution than is present in the existing literature (6.1.2). The solution we will develop is that models reflect aspects of what they model through processes of their genesis. Furthermore, they are judged to be similar by humans, who recognise and evaluate patterns between models and the modelled. Thus we are able to recover the importance of empirical evidence in modelling, and the importance of constant critique in relation to the original phenomena (subsection 6.1.3).

The characterisation of modelling (Section 6.1) provides the basis for discussion of how we should evaluate models of classrooms (Section 6.2). We will begin by considering why modelling classrooms presents specific challenges over scientific forms of modelling (6.2.1) and relate these to Morin's (2007) call for a "generalized complexity" (see subsection 2.1.1). By way of demonstrating how complex materialism approaches such a position, we will consider how it undermines focus upon a particular level of analysis (6.2.2), on defining boundaries (6.2.3) and on simple correspondence between models and classrooms (6.2.4). We shall also discuss how teacher experience and reflection should be situated in relation to classroom learning (6.2.5).

Thus the aim of this chapter is to show that our models of classrooms can be situated within a materialist frame and that doing so provides a number of advantages in relation to considering classroom learning.

6.1 Models as Material

6.1.1 The Reality of Models

We are now in a position to develop the argument first sketched out in subsection 3.1.3, that models are part of the material world and as such have influence. The issue we outlined there is that having argued against our understandings having a special place in the world, or belonging to another realm, we need to account for how they relate to the world around us. We have already situated our understandings as within the material world (Chapter 3). Furthermore, we have suggested that our understandings are formed through experience in the material world (Chapters 4 and 5). We must now explain how our models relate to the phenomena they model.

Firstly, we must clarify the terms 'understandings' and 'models' and the distinction being made between them here. In the introductory chapter to this thesis we adopted the term 'understandings' as suitably broad to capture both the representations that people *within* complex systems possess, and the representations people have *of* complex systems (see 1.3.3). In light of the position developed across Chapters 3, 4 and 5, we see that our understandings have a material basis and are always within complex systems. Understandings have been characterised as the configuration of the brain and body within a specific context. Whereas understandings are associated with individuals, we defined models as also including verbal or written accounts or mathematical or computational descriptions of phenomena (see 1.3.1). Given the 'flat ontology' supported in this thesis, we can now see models as also being within the material world. Our models are constituted by both individual understandings and the extended symbolic systems we use, including images, language, mathematics, computer code and art forms.

This immediately stands against the implication from complex realists that our models can approach an objective reality, because we now see that both models and what they model are different material entities (see 2.3.3 & 2.4.4). We are in agreement that social complexity has a reality and will support the call for empirical evidence in research (see 6.1.3). However the subtle but important difference between complex realism and the position developed in this thesis is that we here reject the autonomy of social entities in and of themselves. We cannot support the claim by authors such as Byrne & Callaghan that social entities across all scales have causal influence:

> "The reciprocal/recursive nature of causality in complex systems is an essential characteristic of such systems and their relationships. In the social world this is not

just a matter of individuals, the micro fallacy, but also of institutions and other social collectives having external causal powers in relations to entities which also have causal powers in relation to them." (Byrne & Callaghan, 2014, p. 180)

To explain their position, Byrne & Callaghan give the example of how UK welfare reform is currently premised on getting more people into work, but this has a reciprocal causality with the need for a more 'flexible' workforce prepared to do low paid jobs. Thus, they argue, there is a reciprocal causation between the economic situation and the political drivers for change within the labour market. If we take government policy and the labour market as social entities, they can be seen as influencing each other. To develop an example more relevant to this thesis, consider the influence of a change in educational policy on an individual classroom. Under Byrne & Callaghan's formulation we might see a reciprocal causality between policy makers and classroom practice.

There is indeed causal influence between policy and practice, but this is not because of the autonomy of these aspects of the world. The key is in recognising policy makers and practitioners as people who interact with (and within) the material world. A politician will be influenced by their understanding of classroom practice and this understanding should be seen as having developed through their direct experiences, discussions and engagement with other artefacts. Policy writing is a response to the context, conditioned by these experiences. As we know, policy is written without exhaustive experience of classrooms. Conversely, a teacher will respond to a policy based upon their impressions of it (including its technical aspects, their attitudes to the policy makers, the responses of others etc.). A policy is constituted by the understandings that people have of it and its encoding in symbols, media and artefacts in the material world.

Byrne & Callaghan talk of a "micro fallacy" in assuming that the situation can be reduced to the interaction of individuals and we have already agreed that this is not possible. However, we do not need to afford social entities an ontological status as distinct from the material world. Complex realists give social entities causal powers because they are primarily concerned with upholding the capacity of social science methodologies to provide insight, and in order to argue for the importance of relating models to the phenomena they model. The desire for "a flexible realist ontology" is born of the need for models to relate to real phenomena, but also an acceptance that the social world is complex. However, there are two issues with their solution (detailed in Section 2.3). Firstly, they do not go far enough in recognising that our models also need to be situated within those complex systems. Secondly, they overstate the reality of social entities by giving them causal powers of their own, rather than recognising the key role that humans play. This has the potential to obfuscate the situation at hand.

A hypothetical example will help to explain this second point. Take a study of a particular school in which the performance in summative exams of each pupil at 16 years of age is compared to their performance in exams at 11 years old. Using national data would allow the calculation of a 'value added' score for each pupil, compared to average progress made by pupils nationally. If those value added scores were then related to the classes pupils had been in between the ages of 11 and 16 we could use regression analysis to develop an 'impact factor' for each class. In this sense, a social scientist is able to claim that a classroom environment has an influence on pupil outcomes; a particular class may have scores 5% higher than average progress predicts. Complex realists might therefore claim that by looking at the real system we can see the causal influence of class membership on pupils. This is an abstraction however.

Closer analysis reveals several modelling assumptions: that exam results alone indicate impact (which is not the same as learning); that it is just class membership that is having influence (compared to parental influence or attendance for example); that the average impact is meaningful; that regression allows the impact of having been in different classes over the years to be separated. The actual influence of a classroom context on an individual is complex such that we cannot fully describe it. Developing a relationship between class membership and average 'value added impact' therefore is not us capturing the reality of the situation: it is an abstraction, a model. The point is that whilst the model has a relation to the system at hand, it does not represent it 'as it is'. It is potentially harmful to consider a model as an authoritative truth.

How then should we characterise models? A model has a material basis in the brains of the modellers and the artefacts and symbols they fashion, be they images, drawings, presentations, research papers, computer programs or even art forms such as sculpture, theatre or dance. Models correlate to the phenomena they represent, but we should not see 'representation' as a direct link between the two. Models are emergent from the thoughts and actions of people who experience a phenomena; they have a unique material reality of their own. In subsection 3.1.3 we used the example of a photograph as a model of a scene and we can further develop that now. At the moment a photograph it is taken the pattern of light is either incident on a film and causes a response of chemicals, or is incident on a digital sensor and causes an electrical current. This is then processed by chemicals or computer to produce a photograph. There is no supernatural link between the photo and the scene at the time it was taken. It is a material response, emergent from the complexity of the social sphere. A computer simulation, verbal description or theatrical performance is not created in a specific moment as a photograph is, but nevertheless can be seen as emergent from the circumstances of its production.

Models are material patterns within complex social systems, they have links to the phenomena they model but are not accurate reproductions of it. We will develop the implications of this over the rest of the section.

6.1.2 Models and the Virtual

Seeing models as separate material entities begs the question as to why some models are better than others. A first sketch of the solution to this was provided in 3.1.3 and rests upon our ability to recognise similarities between phenomena and models. To develop such an argument further we will contrast it to DeLanda's interpretation of Deleuze, which is well respected within the complexity literature.

In considering models of complex systems, DeLanda (2011) takes cues from Deleuze's extensive use of mathematical and topological concepts to relate virtual causes to *phase-space* and *attractors* (both introduced in subsection 1.2.1). DeLanda argues that as a system develops, aspects of the phase-space are *actualised*, that is, the system develops according to movement within a space of possibilities[70] (DeLanda, Protevi & Thanemet, 2004). This space of possibilities contains 'virtual' attractors[71] toward which 'actual' systems tend.

Attractors structure the space of possibilities and so DeLanda uses Deleuze's notion of the virtual to assert the importance of attractors in guiding how the world (social and natural) develops. This therefore provides an account of why there are repeated patterns in the world. The question to be asked though is how this avoids being another dualist account, requiring a supernatural world of attractors.

> "The solution to this problem, as DeLanda makes quite clear in general terms, is to emphasize the notion of active transformation and to work out ways of recognising that which is invariant" (Holdsworth, 2006, p. 147)

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[70] In relating 'possibilities' to phase-space, DeLanda attempts to remove the connotations of possibilities existing within another realm (see 3.2.5).

[71] As noted in subsection 3.2.5, DeLanda (2002, 2011) defines attractors in terms of "capacities" and "tendencies". "Capacities involve a much larger set of possibilities than tendencies because entities can exercise their capacities in interaction with a potentially innumerable variety of other entities." (DeLanda, 2011, p. 20)

DeLanda is careful to promote the importance of genesis in all actual systems, which determines how they develop and what makes them individual. He draws on both complexity theory and Deleuze's work here. In relation to the former, he notes that following Prigogine's work we know that chance events or fluctuations cause structural changes (bifurcations), which alter the future trajectory of the system. In adapting Deleuze's work, he argues that:

> "The identity of any real entity must be accounted for by a process, the process that produced that entity... When it comes to social science the idea is the same: families, institutional organizations, cities, nation states are all real entities that are the product of specific historical processes and whatever degree of identity they have it must be accounted for via the processes which created them and those that maintain them." (DeLanda, Protevi & Thanemet, 2004, p. 2)

So DeLanda argues that there are attractors in the material world which condition, but do not determine, how an actual system will develop through chance events and historic contingency[72].

We are now in a position to situate models within DeLanda's account. DeLanda (2011) explains that when a model reproduces the behaviour of a phenomenon, it is because the model and the phenomenon have similar attractors, despite different mechanisms of emergence.

> "a mathematical model can capture the behaviour of a material process because the space of possible solutions overlaps the possibility space associated with the material process. The two possibility spaces need not be identical… A sufficient overlap can nevertheless exist because the singularities that structure both spaces are independent of the causal mechanisms in a process and formal relations in an equation." (DeLanda, 2011, p. 19)

There are a number of issues with DeLanda's account of modelling. Firstly, around exactly what attractors are; how are they manifest in the real world? Secondly, around why they should be similar in systems with different processes of development; how do spaces of possibility overlap?

In DeLanda's account of bifurcation we see that tendencies and capacities change as the actual system follows a particular trajectory:

[72] This makes use of Deleuze's notion of 'genetic cause'. See 3.2.7.

> “which specific distribution of attractors a system has available at any one point in its history, may be changed by a bifurcation.” (DeLanda, 2002, p. 66)

So attractors are dynamic and, we assume, historically and contextually specific. This begs questions as to how tendencies and capacities are to be considered as ‘virtual’ and where attractors reside. Such questions are unresolved in DeLanda’s work and this leads to a suspicion that DeLanda is conceiving of the virtual as some ‘other world’, despite his claims that it is real. It is also rather serendipitous that the contemporary notion of phase-space should describe the way the world works. Byrne & Callaghan notice this also:

> “DeLanda (after Deleuze) makes great play of terminology derived from topology including the notions of manifold, singularity and attractor. For us this is a turn too far towards platonic assertion of the domain of mathematics as the domain of the real.” (Byrne & Callaghan, 2014, p. 157)

DeLanda is trying to explain why phenomena and models of them have similar behaviours, despite upholding Deleuze’s insistence on the uniqueness of generative processes. Whilst we might propose that all ice has a tendency to melt in the same way, this does not explain why a computer simulation of ice melting runs as it does. DeLanda (2002) develops the notion of “mechanism independence” to explain that there are many different actual causes which would lead to the same emergent outcomes. Interestingly, Sawyer (2004) independently[73] develops the notion of “multiple realizability” to account for how social situations such as “being a church” or “having an argument” have multiple causal mechanisms which lead to the same state, yet may be wildly different. Both DeLanda and Sawyer are seeking to explain why there are patterns in the world which, on closer inspection, emerge in very different ways. However, inventing the terms “mechanism independence” and “multiple realizability” serves to highlight the problem rather than provide an explanation.

Understanding the role of chance, history and context in the development of complex systems highlights a difficulty in explaining why we see similar forms in vastly different systems. DeLanda, in drawing on Deleuze’s ‘flat ontology’, wishes to avoid a reliance on a world of ‘possibilities’ (see 3.2.5), or on a supernatural link between models and what they model. The insistence on mathematical attractors being real and somehow common across systems does not provide an adequate replacement however.

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[73] Recall that Sawyer (2004, 2005) describes a ‘social mechanistic’ position (see 2.3.2).

6.1.3 Evaluating models

In subsection 4.2.3 we argued that the reason Proust's narrator is reminded of Venice when he sees cobble stones is because his brain has a conditioned response to cobble stones that evokes related memories. We thus overcame Deleuze's need for virtual differences by recognising the capacity of humans to respond to similar patterns. This is also the key to describing the success of models. In short, we recognise patterns which we consider to be similar.

To describe why a model or description might apply to a number of different classrooms, we need to carefully delineate three influences. Firstly there are processes of social reproduction which will result in classrooms containing shared features. We touched upon these in Chapter 5, where we considered replication of behaviour, expectations and associations. Whilst we have only touched upon the processes involved, it is possible to see that classrooms look similar across the world partially because of replicated patterns of association: classrooms usually have desks, a teacher, a timetable and a curriculum. People draw upon their experience and expectations in shaping their environment.

The second influence on the success of models however is our capacity to recognise patterns between very different systems. Returning to our simple example, recall that a photograph reproduces a pattern of light from the scene that it portrays; however in some circumstances a map would be more useful (see 3.1.3 and 6.1.1). For a model or description of classroom learning to be deemed useful, it must have coherence with our experience of classrooms in some way. The relationship between the model and the phenomenon is determined by us; we as observers conclude that the model and the phenomenon are similar in an aspect that we find important. This can be explained by (but not reduced to) the responses of neural structure to similar patterns: patterns of light in an image; patterns of behaviour; patterns of association in a description. So our brains allow us to see, and judge, coherent patterns in very different systems.

The reason for claiming only a 'coherence' between the model and the phenomenon is to allow for the all too common case that models do not correspond to experience in actual classrooms, but to other models and descriptions that have been experienced. As we saw in relation to scientific modelling, the concern is often for an 'internal consistency' between models rather than direct empirical evidence (Section 2.1). Here we will support Byrne & Uprichard's (2012, p.124) argument "that materiality needs to be brought back and made central in discussion about social causality."

The third factor which relates models and the phenomenon they model is the process of their genesis. In a photograph the pattern of light which is encoded in the photograph comes from the scene. The pattern is an abstraction, not a full recreation of the scene, but it encodes something that we deem useful. The best models have processes of genesis which draw salient features from the original phenomenon. However we must remember that they are still abstractions and their value is still determined by us.

Consider a researcher developing a network model of a classroom. When the researcher draws a line between two people in a diagram, they are not representing a relation which exists 'out there' in the world, or one which exists in another realm, they are producing a model. The line, the model, is the product of the researcher's brain at the moment they make the link, and corresponds to a pattern they have seen, perhaps a teacher-pupil interaction. The researcher may make further lines, between symbols representing the teacher and other pupils, and produce a network model of teacher-pupil interaction in a lesson. This hypothetical network model is built up by the researcher seeing repeated patterns within a classroom. Of course, each teacher-pupil interaction is different in its detail, but the researcher nevertheless encodes them with a line. Each of the three influences we have discussed plays a role here. The teacher-pupil interactions are likely to be influenced by the expectations that teacher and pupils have, which in turn will be based upon their previous experiences. Patterns such as raising a hand to speak, ways of responding to questions and expectations that teachers have 'the answer' are reproduced in classrooms, despite each instance being unique. The researcher, based upon the understandings they bring to a classroom, will deem certain aspects of the classroom to be noteworthy. They will then encode what they see in a line: a process of genesis by which a model is developed that the researcher considers to replicate a salient aspect of the phenomenon.

To judge a model as successful, it must recreate some important aspect of the original phenomena. In a materialist frame we can see that models and the phenomena they model are both material entities. This means there is no link between models and a separate realm of ideas, nor do we need to claim that they have similar attractors in phase-space. We just need one material entity to be similar enough to the other for our brains to have a similar response to them.

We are thus in a position to propose that if a model recreates more of the original phenomenon, then we are able to judge it as a better model. When a description of a classroom is based upon other descriptions of classrooms, rather than upon actual experience within a classroom, we can see that the model loses its correspondence to classrooms. This is not to say that models which contain more empirical evidence are 'more realistic' (see 2.3.4). Models are themselves material entities with their own complex dynamics. However, we should evaluate models through comparing them to actual classrooms.

> "In short, the standard of judgement as to whether the model is good or bad is grounded in how well the model answers our questions about the world of people, places, and things." (Casti, 1997, p. 46)

6.1.4 The Ethics of Patterns

Cilliers (2004) contends that modelling complex systems is necessarily an ethical act, because our understanding goes on to shape actions (see 2.2.5). The position developed within this thesis provides a foundation for this claim, by showing how models are material entities themselves, situated within complex social systems. So a model has the capacity to influence action because people are able to learn from the words and symbolic forms which constitute it. Patterns of action and association that are encoded within a model may (or may not) be reproduced. An account of the ethics of modelling classrooms lies beyond the scope of this this thesis. However, we will briefly show how Deleuze's position, which we have drawn on in developing a materialist position, supports the continual comparison of our models with the world we have experience of.

Deleuze rejects the possibility of pre-determined 'moral' action in favour of 'ethical' agency in each moment (Byrant, 2011; Spangenberg, 2009). To return to the terms introduced in subsection 3.2.2, Deleuze suggests that ethical action is to be achieved through overcoming the "image of thought" by engaging instead with our "immanent" experience[74]. The point is that Deleuze sees our understandings as situated within a coherent system of thought which we all inhabit:

> "It's just like theology: everything about it is quite rational if you accept sin, the immaculate conception, and the incarnation. Reason is always a region carved out of the irrational – it is not sheltered from the irrational at all, but traversed by it and only defined by a particular kind of relationship among irrational factors. Underneath reason lies delirium and drift." (Deleuze, 2004c, p. 262)

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[74] This can be read in several threads in Deleuzes work, around 'desire' (Smith, 2011), posing 'the right problem' (Byrant, 2011), 'experimentation' (Jun, 2011). See 3.2.3 for a fuller account of immanence in Deleuze's work.

If we focus on models, we can see that they too are "carved out of the irrational" in the sense that they are abstractions of the material world. If we build models in relation to other models then, in Deleuze's terms, we quickly enter into an "image of thought" which has no relation to classrooms. Deleuze's suggestion that we should be "immanent" to our experiences can be grounded in a more concrete account of how we should critically evaluate the relationships between our models and the classrooms they seek to model.

This requires some clarification in relation to this thesis, where we have argued that people recognise patterns within the material; we need to consider how models relate to these patterns. In Chapter 4 we considered how the brain adapts to stimuli and forms distributed representations of patterns in the world. In Chapter 5 we then considered how these patterns are reproduced through our behaviour and symbolic language. Although we may develop a model of a specific moment, most commonly researchers are trying to capture something which is common to different situations and therefore we can contend that models relate to patterns discerned in the world. However we must clarify how seeking patterns in the material world differs from a positivist epistemology in which underlying relations or laws are sought. Furthermore we must consider the ethical implication of seeking patterns in the social sphere.

Whilst patterns have a material basis, they are never the same twice. A key argument of this thesis is that our understandings of the world come from 'difference and repetition' of patterns in the world around us. Patterns are therefore amorphous in the sense that they cannot be pinned down and fully described, despite their material basis. Any act of describing a pattern we see in the world is therefore a model: an abstraction from experience. For example, we might confidently propose a particular group of pupils will perform better than another group in academic tests, and this may be true over a number of tests. The danger comes from therefore concluding that one group is necessarily better than the other (as happens when we label a group as a 'top set'). The pinning down of a pattern of data into a model, and a label, has the potential to obfuscate understanding of how specific pupils in each group actually achieve comparable scores. Furthermore, a teacher may treat the groups according to their label, or the pupils within the groups see themselves through that label. The model, based on an abstraction becomes influential in itself.

Complex materialism provides a basis for seeing that this is because a model is a material entity and has potential influence on the system. However, our discussion of patterns does not imply that we can pin down the patterns which are reproduced and provide full explications of them. Each pinning down is the development of a model, and each model has the potential to obfuscate and do harm. Patterns have a material basis but are irreducible and are constituted by a series of different but repeated instances, each in a unique context. Deleuze's suggestion that we should draw on our "immanent" experience can be interpreted within this thesis as recognising that any model, any description of a pattern, is an abstraction and misses the complexity of the situation at hand.

In this section we have characterised models as material entities which may themselves go on to influence action. We will now turn to how characterising models in this way can help in investigating classroom learning.

6.2 Understanding Classrooms

6.2.1 Models of Classrooms

There is considerable work being done in developing methodological approaches in relation to complex social systems (e.g. Byrne & Uprichard, 2012, Edmonds, 2015). Whilst this thesis is not primarily concerned with methodological issues, in this section we will draw together the insights which have emerged from the theoretical discussions thus far, with a view to further developing the implications of complex materialism[75]. As such, this chapter and Chapter 7 take up the second focus of this thesis: evaluating the implications of complex materialism for how we consider classroom learning.

Throughout this thesis we have been critical of accounts which draw upon complexity theory by attempting to adopt terms from the natural sciences and apply them to social situations. For example, in subsection 1.3.3, we argued that we cannot extrapolate from a concern for interactions to "a new, complexity science of learning and education" (Jörg, Davis & Nickmans, 2007, p. 145), and in 4.2.2 we saw that Engstrøm & Kelso (2008) move from espousing the utility of considering phase transitions to a claim that all binary opposites can be understood in this way. The issue is that it is not enough to utilise the language of complexity or rely upon analogy or metaphor. To describe classrooms as complex requires an explication of how emergence occurs in a particular setting. Whilst the exact causal mechanisms will always be elusive, providing an account of what exactly we consider to be emergent, and what influences the situation, allows the development of models which can be evaluated through their relation to experience in classrooms.

Developing models of classrooms presents specific issues which we have touched upon already. In Section 1.3 we presented the problem of classrooms containing conscious 'agents'. We have now developed an account of how people within classrooms have distributed representations of the world, in that they are each conditioned by their past experiences and are sensitive to context. Another key issue is how we might define the elements of a classroom within a model. In building on a materialist position and developing an account of how symbolic forms and patterns of behaviour and association affect humans, we see that we cannot ignore discussion of meaning in complex social systems. So whilst a network model might allow abstraction of an interaction between two people, that interaction will be defined by the meaning that each person attributes to it. A researcher cannot reduce meaning to its material basis. Over Chapters 4 and 5 we have seen that goals, motivations, relationships,

[75] As will be discussed in Section 8.3, these implications can only be developed further in relation to real classrooms.

body language, mimicry, coordinated movement, position in a room, empathy, group structure, word distinction, and visual processing all influence human learning. Complex materialism implores us to accept that 'scientific' approaches are insufficient in describing social complexity. We cannot sit outside of a social system and reduce the understanding of others, nor can researchers escape their own interpretations of the situation at hand. Every aspect of a classroom has a material basis yet we cannot engage with it in those terms. We must engage with meaning 'on a human level', drawing upon our own experiences and interpretations.

Whilst we will not fully develop methodological issues here, we will draw attention to how complex materialism supports Morin's (2007, p.6) call for an "epistemological rethinking" (see subsection 2.1.1). Complex materialism suggests that we will always see a situation through the lens of our prior experience and the patterns of understanding we have inherited. It also highlights specific areas in rethinking how we characterise models. We will develop this through the examples of how complex materialism allows us to reconsider levels of analysis, drawing boundaries and correspondence between models and variables. We will then consider how teacher understandings, as a particular process of modelling, might be reframed.

6.2.2 Levels of Analysis

In subsection 2.3.2 we saw that complex realists have difficulty in resolving what 'level' of analysis should be considered real in social systems. The issue at hand is that researchers consider it important to define a 'level of reality' upon which they focus their models. For scientists this might be at the statistical level, the level of agents or the level of network relations (see Section 2.1). Complex realists instead assert the reality of all levels of analysis, rejecting bottom-up and top-down approaches in favour of seeing real causal links between subsystems and with the environment (Byrne & Uprichard, 2012). Within the literature there are a number of further attempts to resolve the issue of emergence on different levels of complex systems: Davis & Sumara (2006, p.91) consider classrooms as "nested" complex systems with different levels of reality developing over different timescales (see 2.2.2); DeLanda (2006) develops "assemblage theory" which aims at accounting for how people, organisations, cities and nations can be seen as having mutual causal influence upon each other; Sawyer (2004) describes a 'social mechanistic' account of emergence from agent interactions.

This thesis develops a different position. By adopting a materialist frame we can see that at a fundamental level the complexity of a classroom should be seen as the interaction of matter[76]. However, humans cannot reduce classrooms to this level. Instead we respond to, replicate and manipulate patterns of stimuli across all scales. In Section 6.1 we developed this to argue that our models are all extractions which have their own existence. The implication of this is that statistical equations, agents, network relations and macroscopic social entities (i.e. classrooms) are all human abstractions. They have material reality in the brains and social artefacts we use, but there is no reason to favour one level of reality or fundamental 'unit' of analysis. Complex systems are a hodgepodge of heterogeneous elements interacting across different temporal and spatial scales.

Complex materialism thus frees us of the need to define a single level of reality within our descriptions of classrooms by recognising that all of our descriptions are abstractions. The models discussed in Section 2.1 all have a specific focus: statistical relations; agents; network relations. We must recognise that this is not because of the autonomous reality of these levels, although modellers may imply as such. Instead this is born of the way the existing literature considers causal relations only on a particular scale.

DeLanda (2002, p. 120) argues that the "deductive-nomological approach" in science means that when B is seen to follow A, scientists assume A causes B. Deleuze's (1991 [1953]) reading of Hume suggests that these are instead regularities which result in an inductive link between them. Here we can develop this further in proposing that seeing A followed by B allows adaptation of our neural networks to expect B each time we see A. We can tentatively suggest that scientific models tend to focus on a single level of analysis because they are implicitly linked to an epistemology of discerning causal mechanisms. Reducing a situation to a causal mechanism neglects the unique and historically contingent nature of complex systems. So whilst a teacher praising a student may lead to a particular response, the response of other pupils in other settings might be vastly different. As such, complex materialism promotes a rethinking of causal processes being focused upon a specific level of analysis and instead recognises the influence of heterogeneous elements across scales.

6.2.3 Cases and Boundaries

Social scientists are of course aware of the limitations of reducing situations to a single level of analysis. Thus, approaches such as case study have been linked to complexity because they allow the influence of a greater range of heterogeneous elements on learning than many

[76] In the broadest sense of the term 'matter', to include light, energy, vibrations, etc.

scientific approaches would (Byrne, 2005; Hetherington, 2012, 2013; Haggis, 2008). By allowing the influence of patterns of stimuli, this thesis supports the inclusion of a broad range of influences, on all scales, in describing how learning emerges. However, whilst not necessarily focusing on a specific level of analysis, case study is still plagued by the related issue of defining boundaries:

> "Part of the problem in defining the case in complexity-theoretical research stems from the open, unbounded nature of a complex systems perspective, and relates to the problem of complexity reduction. Choosing boundaries to set around a case entails focusing in on particular aspects and thus excluding other aspects and therefore reducing the complexity of the case." (Hetherington, 2013, p. 79)

Boundaries are usually cited in a temporal and spatial sense to define a system for study. Therefore when we focus on a classroom we set the systems of the whole school or the national school system as outside of the boundaries of study and ignore or reduce their influence.

In subsection 2.2.3 we saw that Cilliers is careful to define boundaries when discussing complex systems, however in Chapter 3 we argued that when Cilliers draws on Derrida he elicits notions of 'otherness' and what is outside of the system of meaning. Drawing on complex materialism we are now in a position to argue that such a notion of boundaries is outmoded and should be overcome. Whilst Hetherington is careful to not define boundaries in a strictly spatial or temporal way, the implication cannot be escaped; her description invokes a sense of limits which tends towards ignoring the 'gaps in between' what is being included in a case. Reference to a boundary implies that we are capturing everything within it and we can no longer support this view of models as representing a classroom 'as it is'.

Recognising that a model is a separate entity to the phenomenon we are modelling highlights that it is an abstraction. Once again drawing on the differences between Deleuze's position and that inherited from Derrida (see 3.2.7), we are able to see that models are emergent from the contexts in which they are developed; they have an existence and influence of their own. Thus characterising boundaries as able to define what sits inside or outside of a model or description, rests upon a view of representation which can no longer be upheld.

6.2.4 Models Corresponding to the World

Arguing against simple representation within models also changes the criteria for evaluating them, because we are no longer tied to each aspect of a model representing an aspect of the modelled system. So in developing a network model to consider the influences on learning (Thagard, 1989) or to describe interaction in a classroom (Carolan, 2014) the links between influences or people need not be fully qualified and resolved and could, for example, be based on report of relationships by participants (Paradowski et al., 2012). Likewise the use of parameters in dynamic coordination models to show phase transitions does not require specific understandings of the meaning of the parameters (see subsection 4.2.1). So when Smith & Thelen (2003) explain the A-not-B error using a "dynamic field" or Kelso et al. (2013) develop variables which model brain activity, but have no specific neurological correlate, we need not assume that one will be found. These modelling features are abstractions.

So too with dynamic systems models which describe interactions within the classroom. By developing coupled equations for the interaction of teacher and pupil, Van Geert and his colleagues have developed elegant models of *scaffolding*, whereby a teacher supports a pupil in learning (Van Geert & Steenbeck, 2005), of the development of reflective behaviour over time (Van Geert & Fischer, 2009; Fischer, 2008) and have modelled the developmental mechanisms described by Piaget and Vygotsky (van Geert, 2000; 2008)[77]. These models, like dynamic coordination models, utilise parameters which need not have a specific correlate in the modelled phenomena:

> "The point is not whether phenomena like reflective judgement or intelligence are of the kind of physical phenomena the magnitudes of which demonstrably vary in accordance with a real-number line – it is most likely they are not. What is at stake is whether variation in these phenomena can be sufficiently approximated by a real-number line to make the application of dynamic systems model more than an empty exercise." (van Geert & Fischer, 2009, p. 317)

Dynamic systems models are deliberately non-representational, because this overcomes the need for simple causal mechanisms, instead recognising emergence from interactions and the environment. We will return to what van Geert & Fischer (2009) call "unsolicited ontological claims" in relation to how contemporary literature characterises 'concepts' (section 7.2.3). Here though we are able to support the use of model parameters which do not have obvious

[77] We will consider these development mechanisms further in subsection 7.2.4

correlates in classrooms, as well as rejecting the need to focus on a specific level of analysis or to define clear boundaries.

6.2.5 Teacher Understanding

There is an obvious tension between wanting models and descriptions to be supported by empirical evidence and the acceptance that models are abstractions, with elements that have no obvious link to the phenomenon being modelled. The issue at hand is how we can generate models which are of greatest utility in describing classroom learning, without appeal to representation. This is not just an issue for researchers however, and is of importance to teachers in evaluating and improving their lessons:

> "Evaluation is about what has worked as a basis for saying what will work" (Byrne & Callaghan, 2014, pp. 195-6)

This brings us to reflective processes such as those described by action research. Without defining it fully here, action research can be seen as a cyclic process of teacher action and reflection on action, which is aimed at improving practice through better understanding it. Action research is seen as a "living, emergent process" (Reason & Bradbury, 2008, p. 4), or as developing "living theories of practice." (Whitehead & McNiff, 2006, p. 2). This leads several authors to argue that it is complimentary to complexity theory (Davis & Sumara, 2005; Sumara & Davis, 2009; Phelps & Hase, 2002; Phelps & Graham, 2010; Boulton, 2011, Wood & Butt, 2014). These authors see our understandings as emergent within complex systems, which we have supported within this thesis. However, they then make a leap in arguing that because classrooms are complex systems, we can best describe them through the emergent and participatory approach which action research implies. This needs careful analysis.

Both in relation to action research, and also in relation to case study (Hetherington, 2013; Byrne, 2005), it is argued that because a broader range of registers, across a broader range of scales are included, these approaches are 'more complex'. As such, it is claimed that they are able to better model complex social systems. In the last subsection we supported the importance of engaging with heterogeneous elements of a classroom. However, a model being emergent from practice is not enough to guarantee it is a useful representation of that practice. The argument that a 'more complex' model is better for describing a complex system again implies representation (see 2.3.3). In recognising models as material abstractions we see that a model being complex and a situation being complex does not mean that the former is best placed to describe the latter. A football match and a thunder storm are both complex, this does not mean they are alike.

However, further dangers lurk in supporting models through appeal to their complexity. For example, when Phelps & Graham (2010) use complexity theory as a justification for introducing “noise” into classrooms:

> “The ‘action’ in action research might be conceived as an energy input, which in some instances prompts a state of non-equilibrium. From this, new possibilities, and perhaps new stabilities, emerge. Thus, action research might be considered the vehicle to both promote and study such processes.” (Phelps & Graham, 2010, p. 511)

Here we rehearse the objections to Davis & Sumara’s notion of ‘conditions of emergence’ which Phelps & Graham draw upon (see 2.2.2). We cannot impose terminology and models of complexity on a situation and claim that they therefore represent the complexity of that situation (see 1.3.2). There is no justification for trying to manipulate a system based on a general view of complexity. Radford (2007) shows that action research actually aspires to control and simple causality, and that complexity theory poses a challenge to action research. Recognising models as real entities shows that an emergent model cannot be assumed to represent the system it emerged from, nor that it is a good model. We must recall that each complex system is unique.

With complex materialism as a theoretical basis, it is relatively easy to see that models do not provide simple representations of classrooms, because a model is a different entity altogether. What is less easy to resolve is how models relate to multiple instances of similar situations. Drawing on Chapters 4 and 5 we see that teachers will constantly be adapting to their experiences in classrooms, which leads to more nuanced and arguably more effective understandings and models over time. How then are we to assert the importance of continually exposing models and understandings of classrooms to comparison with real classrooms, when we are also arguing that every classroom is unique?

Haggis (2008) argues that in drawing similarities between cases we tend to develop “transcendent” abstractions which link different contextual settings, for example when we code empirical data and assign a categoric similarity to two phenomena. We decontextualize different events and ignore the differences between them. Adopting the theoretical position in this thesis provides a basis for this in the adaptation of understandings and models to experience. The key point is that our models emerge in specific contexts and are therefore in no way guaranteed to be useful in future contexts. We must continually compare these models and the system at hand, in order to critically evaluate the model and its implications.

In Deleuze's terms, we should be 'immanent' to the situation at hand, and see how it differs from the "image of thought" we possess (see 6.1.4).

We have noted that there are processes which reproduce patterns of behaviour and association within the social sphere (6.1.3). Yet these are linked by repeated but different processes of genesis, rather than by a universal law or mechanism. Thus a model may develop over time which is useful in describing the patterns we see in classrooms, or in the broader world. However this does not mean we have a more accurate representation of the real world. Models are not just evaluated in relation to the systems they model, but also in relation to their coherence to other models, as well as in relation to the goals and experience of the person doing the evaluation. Fads and trends within educational practice are not always based on evidence (see Goldacre, 2009).

To answer the question posed at the beginning of this subsection, a call for empirical support for models can be reconciled with the acceptance of parameters which have no empirical correlate, through the recognition that all models are deficient. Yet through continual evaluation of their utility (rather than their correspondence), we should be prepared to reject or adapt models and understandings in light of new experiences. Teacher experience in understanding learning is therefore important, because the understandings teachers have will be constantly challenged by their experience in real classrooms. However this does not guarantee a preferable view of learning. In the next Chapter, we will consider contemporary views of learning in this light.

6.3 Chapter Conclusion

In this chapter we have shown that our models and descriptions of classrooms should be seen as themselves part of complex social systems. Models can be seen as abstractions within our brains and the broader material world, which emerge from our interaction with that world. This overturns a view of models as being direct representations of the phenomena they model and thus allows us to situate models within the frame we have called complex materialism.

Models can be linked to the phenomena they model on three counts. Firstly, in that people modify the world according to their understandings of it. So classrooms come to have similar features and activities within them because pupils and teachers bring these expectations with them. Secondly, in the best models there is some interaction between the phenomena and the model as it is produced. A photograph captures light from a scene; a network model encodes a perceived connection between teacher and pupils. However, this does not mean that a model is therefore fully representative of a phenomenon: it is an abstraction. This begs the question as to how a model recreates something of what it models when it may take a very different form. This brings us to the third link between models and the modelled: the capacity of humans to recognise patterns. Across Chapters 4 and 5 we showed that humans are able to respond to patterns within heterogeneous elements of the social world. In this chapter we have applied this in explaining how we come to judge diverse systems as related to each other. For example how a computer model or line drawing could be afforded a meaningful relationship to classroom learning.

Models are thus evaluated according to their utility within the social sphere and this is a normative process. This does not deny the importance of empirical evidence. Generating models from processes which engage directly with classrooms is better than models which have only coherence with other descriptions of classrooms. However, a model being itself complex does not mean that it necessarily captures the complexity of the original phenomena. Seeing models as separate, material entities underlines this point. Drawing upon Deleuze's notion of "immanence" we have proposed that models should continually be exposed to critical comparison with the phenomena they seek to describe. This does not entail every parameter of a model having a correlate with an aspect of a classroom, but it does mean that the utility of models in describing classroom learning is subjected to continual critique.

In recognising that each instance of a pattern is unique we remove the connotation that models capture some universal quality of classrooms. Furthermore, by asserting the importance of human pattern recognition in modelling, and indeed describing it in Chapters 4 and 5, we have overcome the need for DeLanda's virtual attractors which are common across diverse systems, or unhelpful notions of "multiple realizability". Thus we have demonstrated that complex materialism, and considering models as material, has advantages over existing views of social complexity.

In addition to theoretical advantages we have suggested practical advantages of such a position in relation to describing classrooms. As well as judging modelling parameters by their utility rather than correspondence, we have 'opened up' models to the inclusion of heterogonous elements of influence. The requirement of focusing on a specific level of analysis is linked to a particular view of causality, inherent in viewing models as universally applicable. So too have we challenged the notion of boundaries, which is impossible to sustain without connotations of representation. In this chapter we have touched upon dynamic systems models, network models, case study and action research and begun to relate these approaches to the positon of complex materialism.

Whilst not fully developing the methodological or ethical implications of complex materialism, this chapter has used examples to highlight how it might allow the "epistemological rethinking" that Morin (2007) calls for. It has also answered the third criterion we set for a theoretical position equal to the challenge of describing classrooms in Chapter 2, by showing that a materialist position is able to situate our models of classroom learning within complex social systems. This is advantageous to researchers and teachers alike.

7 Implications: Understanding Learning

7.0 Chapter Introduction

In Chapter 6 we situated models of classroom learning as themselves within social systems. We also explained how models of classrooms should be characterised as material entities themselves, and how they can go on to influence action and understanding. As such we argued for the need to constantly critique our models of classrooms in relation to actual classrooms. In this chapter we will consider existing notions of learning and compare them to the theoretical position developed in this thesis, in order to show how complexity sheds new light on learning within classrooms.

From the outset we should be clear that 'applying' a theoretical position can only ever be a process of comparing existing models about the way a system functions with another model. Following the development of complex materialism in this thesis therefore, we are making a claim that a classroom is a hodgepodge of heterogeneous elements from which learning emerges. In Chapter 4 we developed a model of learning as the adaptation of brain and behaviour to the experiences that a person has. In Chapter 5 we also considered the role of repeated yet unique patterns in allowing shared understandings. As such this chapter compares models of learning within the existing literature with the model of learning developed in this thesis: learning as nonlinear, material and contextual.

In Section 7.1 we will consider existing models which characterise learning as a linear process. This will centre on concerns for 'effectiveness' in the sense of learning objectives being fulfilled, or classroom processes identified as having a direct causal influence on outcomes. We will argue against this formulation of causality.

Section 7.2 will challenge notions of learning as being primarily a process of mind. We will draw attention to the impossibility of separating 'concepts' from processes in the brain and body, but furthermore from material patterns in classrooms. Indeed, some modellers deliberately avoid defining concepts on account of the difficulty in doing so. We will show how complex materialism undermines existing notions of learning as "conceptual change".

Finally, we will see how describing learning as nonlinear, and undermining the autonomy of mental concepts, challenges existing notions of schooling as the acquisition of facts and skills. We will build upon existing critique of the assumption that curricula represent the broader world (Osberg & Biesta, 2004, 2007; Osberg, 2005; Osberg, Biesta & Cilliers, 2008). In doing so, we will develop an account of 'emergentist curricula' by situating emergence in the interpretation of curricula in classrooms, as well as seeing curricula themselves as within complex social systems.

Thus the formulation of learning (Chapters 4 & 5) and the situating of models as material (Chapters 3 & 6) will be brought to bear on existing accounts of learning. This will serve to both develop the position of complex materialism through its application (focus 1 of this thesis), as well as further expound its utility in relation to classroom learning (focus 2).

7.1 Learning as Nonlinear

7.1.1 The Effectiveness of Activities

As discussed in 1.2.1, the term nonlinear in relation to complex systems refers to the potential for multiple factors to influence a situation, such that we cannot attribute a single cause to a particular outcome: we cannot attribute a linear model of causality. Because of this, a small input may (or may not) have a large influence upon a system, and this means that complex systems are unpredictable over long timescales. In Chapter 4 we developed a model of learning as the adaptation of embodied neural systems to experience, and highlighted the role of context and history in the emergence of new electrical patterns in these neural systems.

We are thus now in a position to underpin the argument made in subsection 1.2.5 that complexity theory offers an alternative discourse to the 'linear' formulations of learning inherent in the National Strategies (DfES, 2003; Ofsted, 2010). We are also now better positioned to argue against the contemporary focus upon 'evidence based practice' and the reliance upon monitoring and continual testing:

> "the view that underlies these approaches is one that characterizes individual students in terms of true scores on underlying latent variables, the variance of which is to a specifiable extent explained by the contribution of educational methods and practices that can be treated as independent variables" (Steenbeek & van Geert, 2013, p. 234).

Radford (2008) also draws attention to this "prediction/control paradigm", which is centred on a 'scientific' approach to learning and schooling. To develop the challenge that complexity presents to such discourses we will consider notions of 'effectiveness' which pervade the education literature. There are however, different accounts of effectiveness and here we shall draw on two: firstly a model of effectiveness in the specific area of practical investigations in school science and secondly to the statistical analysis of classroom practice.

As an example of effectiveness in classrooms, Millar and Abrahams (2009) discuss practical work in school science. They use the model in Figure 7a to describe effectiveness.

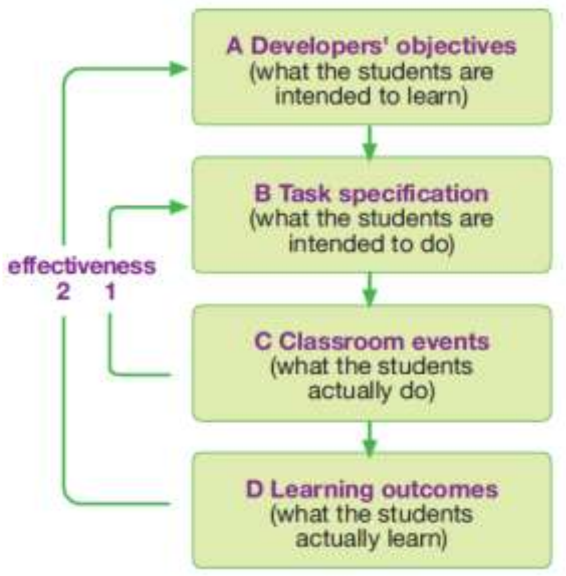

Figure 7a - Model of Effectiveness reproduced from Millar & Abrahams (2009, p. 60)

The objectives are what the teacher intends the pupils to learn, although this may be only implicitly stated. These are then used to design an activity or task. When the activity is implemented, we are able to observe pupils and can then judge how closely pupil actions match what it was intended for them to do. Millar and Abrahams label this as the first type of effectiveness in Figure 7a. However, they note that when people talk of the effectiveness of a teaching activity they are discussing the relationship between the proposed learning, the objectives, and the actual learning, or 'learning outcomes'. This is denoted as the second type of effectiveness in the figure.

Millar and Abrahams discuss the range of different objectives that science teachers may have in mind and also the difficulty of measuring effectiveness, especially within the context of a longer sequence of lessons. However, their discussion simply does not go far enough in recognising the intricate, interlinked and unpredictable nature of learning in practical activities. The learning that takes place will depend upon the individual histories of each of the learners, the dynamics of interaction in the room and the context in which the activity takes place, down to the words used and the weather outside.

We should note that Millar & Abrahams are clearly distinguishing between what teachers intend to happen and what actually happens; they recognise that there is a difference. What is drawn into question by complexity theory is the capacity to make a value judgement about whether the intended learning has taken place. Complex materialism offers a theoretical model with which to counter the claim that teacher objectives can ever be matched by pupil outcomes. Both are part of the same complex dynamic system, so whilst the teacher may develop a lesson plan (a model), it will be constantly interacting with the events in the classroom as they unfold. Conversely, pupil actions will of course be influenced by teacher intentions, but not in a simple way. Teacher intentions and pupil actions do not exist in different realms; they are part of the same real system. As such, evaluating the relationship between objectives and outcomes in a classroom might be seen as akin to evaluating the relationship between a rain cloud and the atmosphere.

Millar and Abrahams are both prominent figures in science education and as such it is not surprising that their model of effectiveness aligns with the process of hypothesis testing in scientific endeavour[78]. However, their model of effective practical work in science is aimed at practitioners (it is published in a journal for science teachers), and it was written in response to a great deal of school science lessons containing practical work which did not aid in making links between skills and understanding (Hodson, 1993, 1996; Abrahams & Millar, 2008). In this context it is useful in providing the starting point for teachers to consider how they use practical work in science lessons. Aiming to improve the quality of classroom activities is not something we should shy away from and this illustrates the potential of a simplistic model to be useful.

However, Millar & Abrahams appear to be conceiving of learning as the acquisition of knowledge or skills as the teacher intends. Learning within a complex system is an emergent process and is therefore unlikely to result in the same knowledge or skill being developed by different people in different situations. This account of effectiveness may obfuscate learning by insisting upon and measuring only some simplistic confirmation of what a teacher is looking for, such as a key word being used or them finding the 'correct' results in an experiment. Part of the issue therefore is that this model of effectiveness promotes teachers seeking control of learning and evaluating their lessons on the basis of pre-determined objectives. There is furthermore a range of ethical implications to this conceptualisation of learning in classrooms. For example, teacher self-efficacy may be negatively affected if they continually see their lessons deviating from their predictions, or managers may rely too heavily on meeting objectives as a measure of teacher performance.

To illustrate this, consider the UK Office for Standards in Education's (Ofsted) suggestion in their Framework for School Inspection that:

> "The most important role of teaching is to raise pupils' achievement. Therefore, inspectors consider the planning and implementation of learning activities across the whole of the school's curriculum, together with marking, assessment and feedback." (Ofsted, 2012)

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[78] Hypothesis testing is most commonly aligned with Popper's (1959, 1963, 1972) view of scientific development.

The implication here is that it is 'achievement', by which they mean examination results, and not learning that is important and that through effective planning and assessment this achievement can be furthered. However, in practice, the majority of school policies respond to such statements by focusing on what is perceived as tangible 'data' to demonstrate pupil progress. Here we see:

> "the tension between rigor and accountability through standards, benchmarks, and high stakes testing on the one hand and more progressive, student-centred approaches to teaching and learning on the other" (DeBoer, 2002, p. 405)

An advocate of learning objectives may argue that with careful 'differentiation' objectives can be made loose enough to accommodate different learning, and may even be 'personalised' so that individuals each take something different from the activity. In contrast to tight prediction and control therefore, we see another extreme in highly personalised learning. Beighton (2013) uses Deleuze's work to question whether we can really achieve individualised learning in a complex system. We interact with each other and with the world and as such complexity exposes "the flawed individualism implicit in the buzzwords of 'differentiation', 'Individual Learning Plans' or 'personalisation' which are supposed to inform practice but can instead make it seem trivial or even banal." (Beighton, 2013, p. 1297). Where personalised learning actually takes the form of pupils being assigned different tasks according to assumptions about their 'ability' we see that they are still reliant upon an assumption of prediction and control that is disputed by complexity theory.

We have shown within this thesis that learning is historically contingent, with each pupil's neural network being different. This makes them sensitive to context and explains why every pupil learns differently. However, we have also considered the reasons for shared understandings: repeated yet unique patterns of association and behaviour. Conditioning pupils to respond in a particular way is possible, but this does not capture the sensitivity of learning. This is not to say that learning is intangible. Many teachers are skilled at probing pupil responses to particular tasks and providing feedback which helps further development. What is being rejected here is the application of simplistic assumptions about learning as a linear and predictable process, and evaluation of lessons being reduced to a simple measure of 'effectiveness'.

7.1.2 The Effectiveness of Classrooms

As well as the use of 'effectiveness' to denote the success of an activity in a lesson, notions of 'effective schools' form a prominent aspect of the research and policy landscape:

> "The pervasive discourse of the 'effective school' and more latterly the 'school improvement' movement with its drive for 'continuous school improvement' – a slogan whose simplistic impossibility wound render it risible had it not been spoken seriously by so many otherwise rational professionals – may impose a narrowly instrumental or technicist agenda… which supresses the search for diversity, creativity and adaptability, thereby reducing its effectiveness." (Watson, 2014, p. 27)

Creemers and Kyriakudes (2008) describe 'educational effectiveness research' as a field with a history of over forty years. Whereas Miller & Abrahams use the term effectiveness to denote 'achieving what is intended', educational effectiveness research incorporates the statistical analysis of different teacher and classroom practices against dimensions of interest such as attainment. In this way they believe it is possible to elucidate what is effective and what is not and thus proceed to develop educational practice in a pseudo-scientific way.

However, Creemers and Kyriakudes (2008) note that the initial optimism in this approach has waned and attempt to identify the reasons for this. They identify six factors which were not originally foreseen within the field:

1) Studies focusing exclusively on teacher effectiveness and those focusing on school effectiveness were both limited. "In addition to the multilevel nature of effectiveness, the relationship between factors at different levels might be more complex than is assumed" (Creemers & Kyriakides, 2008, p. 6)
2) Teachers and schools actually perform differently across different pupil groupings.
3) Different 'effectiveness factors' such as aptitude, instruction, and 'psychological environment' are actually interlinked.
4) Effectiveness research has focused narrowly on mathematics and language acquisition because such things are more easily measurable. Education actually has a range of objectives and as such more sophisticated measures must be used.
5) 'Effectiveness factors' such as assessment policy have been seen as "unidimensional constructs" when in fact assessment policy contains many aspects such as design of assessment instruments, record keeping, reporting etc.
6) Effectiveness research has focused on comparisons of schools at one or two points in time which is not sufficient to capture the dynamic nature of schools.

Creemers & Kyriakudes (2008, p. 9) note that "Teaching and learning are dynamic processes that are constantly adapting to changing needs and opportunities." Yet bravely they spend nearly three-hundred pages attempting to show how statistical models could be made more sophisticated in order to capture this dynamic nature. They develop a comprehensive list of the factors which might influence learning at the student, classroom and school level and explore the use of comparative, experimental and statistical approaches to identify the relative influence of these. Despite enviable attention to detail, the view from complexity theory suggests that they are somewhat missing the point. Educational effectiveness research is not up to the task of capturing the complexity of classroom learning.

As outlined in the introduction to this thesis, the growth of randomised control trials (Goldacre, 2013) and meta-analyses (Hattie, 2008, 2011) within educational research appears to be in response to superficial monitoring regimes such as that of The National Strategies. However, these reductionist approaches, like educational effectiveness research can only be useful if embedded in an understanding of their limitations. Cook (2012) argues that randomised controlled trials and meta-analysis can provide insights into what works, for whom, and in what contexts. However, he cautions that:

> "Educational environments are complex, involving numerous interweaving factors and the sometimes idiosyncratic behaviours of multiple individuals. Research itself is highly context dependent, and strictly speaking, no study's results apply outside of the unique environment within which it was conducted. Therefore, evidence does not speak for itself – it requires interpretation in light of its original context, limitations, and conceptual framework" (Cook, 2012, p. 468)

Biesta (2007) adds to this the argument that focus on 'effectiveness' in educational research overlooks any concern for what is desirable in education:

> "The means we use in education are not neutral with respect to the ends we wish to achieve" (Biesta, 2007, p. 10)

He gives the hypothetical example of physical punishment improving performance, yet teaching pupils that violence is justifiable. We are returned to our argument in Chapter 6 that all models have ethical implications. If simplistic notions of learning become the primary understanding in classrooms or at the policy level then there is potential for real damage to pupils, teachers and schools. Success cannot be judged by assuming data points on a line represent learning; complex materialism provides a theoretical framework which highlights the challenge to such approaches. Learning is sensitive to context and history, but furthermore our models of learning are real entities which interact with classroom practice.

Complexity poses a challenge to assumptions of learning as predictable and controllable. However, narratives around educational effectiveness also rest upon an assumption that learning is about the acquisition of 'conceptual understanding'. We will now turn to situating 'concepts' within a materialist frame.

7.2 Learning as Material

7.2.1 Mental Images

The current national curricula for England list the "conceptual understanding" that pupils must gain (DfE, 2013a; 2013b), exemplifying contemporary concern for concepts. We have already touched upon how concepts and consciousness might be seen as emergent from neural networks (see 4.1.5) and elsewhere that "the core of our conceptual systems is directly grounded in perception, body movement, and experience of a physical and social character" (Thelen & Smith, 1994, p. 141). However this begs the question as to how we might define concepts if they are seen as emergent.

We shall flesh out the issue by here considering the theories of Bruner (1966, 1978, 1983) and Piaget (1929, 1951), who are highly cited within educational literature. These do not present a single view of learning (Shayer, 2003), however we will tentatively suggest that they share a notion of mental representation in which there is some image of reality in the mind. As will already be clear, direct representation is challenged by complexity because there can be no simple relationship between a representation and the represented.

Bruner (1966) describes different modes of representation with which children reason. *Enactive* representation, which develops from birth, is conceived of as unconscious learning associated with muscle movements. *Iconic* and *symbolic* representation however, which first appear in later stages of development, are characterised by a representation of the world which has some correspondence to it. Whilst enacted learning might be thought of as the adaptation of biological responses, iconic and symbolic representations imply an autonomous mental world. The neural network models considered in Chapter 4 do not directly question the presence of mental images; they do however situate them as emergent properties of distributed networks of neurons. This does not deal a deathblow to the utility of Bruner's theory in describing how we learn, but it does undermine the autonomy of these mental representations and instead characterises them as emergent from interactions of matter.

Things are not as clear cut when we consider the often cited work of Piaget. Take his description of the inner world of a child:

> "There is certainly present to the child a whole world of thought, incapable of formulation and made up of images and motor schemas combined. Out of it issue, at least partially, ideas of force, life, weight, etc., and the relations of objects themselves are penetrated with these indefinable associations. When the child is questioned he

> translates his thought into words, but these words are necessarily inadequate." (Piaget, 1929, p. 27)

Here we see an account in which the "relations of objects themselves" are represented in the mind and the implication is that there is a correspondence between the relations in the world and the "world of thought", although the relationship is not a clear one. Piaget's (1951) stage theory of development also treats the manipulation of mental imagery and symbols as the pinnacle of development, suggesting that these are conceived of as processes in an autonomous mind. We have already challenged the separation of sensorimotor learning from 'symbolic' processes of solving problems with gears or with links between words (see 4.2.2).

However, the argument that Piaget sees the mental world as autonomous is obfuscated by his cautious hints that the biological molecule RNA might be the physical seat of learned schema (Piaget, 1974). Whilst the suggestion itself has been discredited, this does illustrate that Piaget was not opposed to considering biological mechanisms underlying mental processes. Van der Veer (1996) also notes that Piaget criticised earlier psychological models for not accounting for the genesis of thoughts and thus Piaget focused on how understandings (schemas) come about through new experiences. Thus Piaget related both the brain and the broader world to the development of the mental world. Much more of Piaget's work could be related to complexity [79] and of course, both Bruner's and Piaget's work pre-date contemporary neuroscience. Nevertheless, what is brought into question by this thesis is the autonomy of the mental world from the neural processes within the brain: we cannot see the mental world as separate from the 'real world' and yet interacting with it. In light of complexity we are forced to re-evaluate what concepts are.

7.2.2 Conceptual Change

The contemporary field of *conceptual change* is of particular interest here, because it deals directly with classroom learning. Conceptual change literature is gathering pace, particularly within science education, where Duit (2009) catalogues over 8000 articles on the conceptual change of both pupils and teachers.

diSessa (2006) charts the development of conceptual change literature since the 1980's and explores how initial research on *misconceptions* gave way to more nuanced models of how pupils' naïve and implicit understandings affect learning. Today, the field is considered to be divided into three approaches to considering concepts (Brown, 2013; Brown & Hammer, 2008;

[79] For example Van Geert (1998, 2000) uses dynamic equations to reconsider Piaget's notions of 'assimilation' and 'accommodation'.

Bereiter & Scardamalia, 2008; diSessa, 2008). Firstly, there are researchers that focus upon misconceptions which are static, predictable and separable. For example, many children believe that rays come from our eyes in order for us to see (Driver, et al., 1994). Such misconceptions are characterised as 'blocking' further understanding and must be replaced or removed. Such a view accounts for many studies in which pupil ideas appear to be resistant to change (Brown, 2013). However, two new approaches developed as many conceptual change researchers moved away from this static characterisation of misconceptions. Both approaches focus on a more dynamic understanding of pupil concepts which may contain a synthesis of learning with what are now called *naïve concepts*. For example, when asked to draw the earth pupils will often draw a circle, but when then asked to draw a human they draw them on a flat surface within the circle (Vosniadou & Brewer, 1992). Two different interpretations of this developed: on the one hand there are researchers who believe that pupils have a coherent understanding of the world, which is generated from 'deeper implicit conceptions'; on the other hand are those that believe that children (and adults) have a range of fragmented understandings, known in the field as "phenomenological primitives" or "p-prims" (Brown & Hammer, 2008). Views of misconceptions as 'object like' blocks to learning, coherent systems of understanding and fragmented partial understandings are thus opposed within the literature. The issue being that in empirical studies of what pupils say and do it is impossible to investigate how they are actually thinking.

Complexity theory provides a dynamic perspective from which to re-examine these different positions:

> "If misconceptions, systems of elements, or fragments are viewed as dynamically emergent structures, the oppositions are lessened, and the integrated view has significant implications for theory and practice." (Brown, 2013, p. 1)

Thus, by seeing concepts from a complexity perspective, Brown sees them as sometimes fragmented and incoherent, but at other times manifesting as a coherent system of understanding (which may contain seemingly static misconceptions). Brown & Hammer (2008, p. 125) go as far as postulating "conceptual attractors" which are surprisingly robust, and that account for empirical evidence that learning is in many cases not proportional to "instructional perturbation"[80]. So learning is a process of moving between semi-stable understandings, which may be fragmented and intuitive, or may contain seemingly entrenched

[80] Heywood & Parker (2010) also define "cognitive conflict" as tension between new experiences and existing concepts in the classroom.

misunderstandings. Seeing learning as emergent reconciles different theoretical positions within the conceptual change field, but also provides a hypothesis for the importance of context in learning.

On the surface then, adopting a complex systems view appears to be a way to significantly advance the field by allowing a range of empirical results to be explained with a single model. However, without an adequate account of how concepts relate to the material world the model of "conceptual attractors" becomes dangerously vague, and rests upon the terminology of complex systems rather than a specific account of emergence. We therefore need to consider how concepts relate to brains and the broader context of the material world.

7.2.3 Concepts and Brains

Within the conceptual change literature there are suggestions that concepts exist as a level of reality:

> "concepts are emergent, arising from a self-organizing process that at a micro level (but at a level still above that of brain processes) consists of ideational interactions that are uncontrollable and unknowable. And these are not insignificant variations that all behaviour exhibits (you never pick up a teacup in exactly the same way twice); they are the very essence of semantic interactions from which emerges a new organization of some part of the conceptualized world. That is the irreducible complexity of conceptual growth, when viewed from the dynamic systems perspective." (Bereiter & Scardamalia, 2008, p. 506)

Here concepts are situated above the level of brain processes but equally not at the level of behaviour. We are thus left with an account of something seemingly obvious but difficult to pin down, namely consciousness. We will not attempt to resolve the ancient problem of defining consciousness here. However, we will challenge how contemporary educational literature separates concepts from the physical world.

In order to develop this challenge it is worthwhile considering how neuroscientists characterise concepts. We have drawn heavily upon Freeman's discussion of electrical patterns in the brain (see Chapter 4). He describes, in a rather general way, how mind is emergent from brain dynamics at multiple levels (Freeman, 1999). Freeman also draws links to existing learning theories, for example in saying that his model of action-response in the limbic system "corresponds to Piaget's cycle of "action, assimilation, and adaptation" in the sensorimotor stage of childhood development." (Freeman, 2000, p. 4). Without engaging with this claim, the relevant point here is that neuroscientists tend to extrapolate from well understood processes in the brain, such as those in the limbic system, to explain a broader conceptual world, such as that described by Piaget (see 7.2.1).

Along these lines, Gallese & Lakoff (2005) provide substantial and convincing evidence that concepts are embodied in the function of the sensory-motor system within the brain, suggesting that "the sensory-motor system has the right kind of structure to characterise both sensory-motor and more abstract concepts" (Gallesse & Lakoff, 2005, p. 1). They survey the particular clusters of action-location, canonical and mirror neurons to support the conclusion that the brain function involved in 'simulating' or imagining a possible action is closely related to the process of actually doing that action. As such they develop a model for what they call "action concepts" as involving the sensory-motor system.

However, they go further in proposing that many aspects of our conceptualisation of the world are linked to motor actions through references to movement. For example, in considering love as a journey: a long and bumpy road; at a crossroads; partners going in different directions, or in notions of grasping an idea or being kicked out of class. They also relate Naraynan's (1997) analysis of action metaphors in economic news: France falling into a recession, being pulled out by Germany etc. Whilst our brains using the motor-sensory system to understand the world is plausible, Gallese and Lakoff stray into unfounded arguments when they claim the autonomy of "basic-level" categories:

> "We have motor programmes for interacting with chairs and cars, but not with furniture in general or vehicles in general." (Gallesse & Lakoff, 2005, p. 467)

These are "the level at which we interact optimally in the world with our bodies" (*Ibid*). This quickly approaches a dualist ontology in which *a priori* mental categories represent the world[81]. More practically however, the choice of what is fundamental seems somewhat arbitrary. Surely 'driving' is a more fundamental embodied category than 'car' as one can drive a car or a lorry through roughly the same sensory-motor understanding? There are clear problems with the extrapolation from sensory-motor function to broader arguments around what Gallese & Lakoff call "natural language". However, Gallese & Lakoff are clear that we cannot view concepts as separate from our brains or surroundings, instead favouring reference to what they call "schemas":

[81] This approaches Kant's position.

> "We have hesitated to call schemas "concepts", simply because concepts have long been traditionally thought of as being direct reflections or representations of external reality. Schemas are clearly not that at all. Schemas are interactional, arising from (1) the nature of our bodies, (2) the nature of our brains, and (3) the nature of our social and physical interaction in the world. Schemas are therefore not purely internal, nor are they purely representations of external reality." (Gallesse & Lakoff, 2005, p. 468)

Such accounts show that neuroscience supports an interrelation between brain, mind and behaviour. This challenges any belief that concepts are autonomous or primary to processes in the material world. Furthermore, it provides tantalising suggestions as to how our brain function contributes to the way we think. If action metaphors can be related to 'imagined moving' via the sensory-motor system, then we can speculate that other aspects of the brain may be involved in 'imagined talking' or 'imagined seeing'. Thus conscious thought is the embodied response of the brain to what might happen. This is supported by the contemporary view that brain functions are 'multi-modal', that is, the same systems are deployed for multiple purposes (Gallesse & Lakoff, 2005). However, these descriptions also highlight our inability to reduce concepts to neural processes alone.

7.2.4 Concepts and Context

Van Geert & Fischer (2009) argue that much of the literature on learning assumes that there are 'mental mechanisms' which cause or produce behaviour[82]. We here join them in arguing against the primacy of mental processes and the separation of thought from action. There is no simple correspondence between reality and 'mental images' which directly represent that reality in the brain. Synaptic adaptations allow for distributed representation such that the relationships between experience and brain structure is complex. This suggests that whilst our concepts cannot be seen as autonomous mental entities, they cannot be direct representations of the world either. Concepts are not a simple encoding of the way the world really is: they are distributed representations that allow us to function in relation to the world around us.

> "if you believe that using a mental term such as concept automatically makes you adhere to the unproved belief that it is some internal representational engine that manufactures behaviour and problem solving, you are making an unsolicited ontological claim." (van Geert & Fischer, 2009, p. 320)

[82] In relation to this, we touched upon Ryle's (2009 [1949]) "Ghost in the Machine" argument in subsection 4.2.3

In critiques of coordination dynamics models, these unsolicited ontological claims are often made in relation to the use of parameters which have no obvious material correlate (as discussed in 6.2.2). Not only does the view of models developed in Chapter 6 support the use of such parameters, but we should also recognise that coordination dynamics models deliberately stand against reliance upon specific mental processes (Smith & Thelen, 2003; Beer, 2000). These approaches see "development as relating to person-context assemblies on various timescales and levels of aggregation" (van Geert & Fischer, 2009, p. 327). The characterisation of concepts as mental entities or simple representations is explicitly rejected within the field of coordination dynamics.

Van Geert and his colleagues build models which account for the development of a person as specified by an array of characteristics in relation to a 'context'; both individual and context are dynamically coupled and co-develop. For example, Van Geert & Steenbeck (2005) develop a model of teacher support (scaffolding) in relation to empirical data from a class of 9 pupils aged between 8 and 10 years, within a school for special needs. The model has obvious simplifications, with level of understanding being related to workbooks being used and pupil-teacher interaction being purely one to one. Nevertheless, such models show that learning can be described through the response of pupils within classroom contexts, without developing a specific account of concepts, relying upon mental mechanism, or even defining concepts.

Having overcome the primacy of any specific level of analysis (see 6.2.2), we are in a position to argue that human learning is best seen as emergent from a range of different scales. The term 'concept' is too closely related to a dualist or dialectic position in which mental processes are separated from brain, but also from the contexts in which those brains act. There is growing evidence that brain, body and behaviour are linked and researchers are developing approaches to viewing these as parts of one and the same system, overcoming the need to refer to concepts. For example Fischer (2008) relates the punctuated development of connections between cortical brain areas with the development of cognitive skills over time. Another approach is to develop network models of the various influences upon a learner at a particular moment:

> "for thinking about educational processes the most useful type of representation is a connectionist network in which all or some of the nodes are assigned identities as people, ideas, facts or other meaningful entities." (Bereiter & Scardamalia, 2008, p. 506)

Thagard (1989) develops perhaps the most comprehensive model of this type, in which a network represents the relationships between different propositions and observations that a pupil may make. Essentially, the network then settles on a solution, a 'decision', based upon the coherence of propositions in the network. Thagard's model of explanatory coherence was published with no less than 27 commentaries pointing out the difficulties with such a model, and is still the subject of critique (e.g. van Geert & Fischer, 2009). However it does raise the possibility of seeing decision making as emergent from a range of heterogeneous influences.

In the above quote, Bereiter & Scardmalia characterise people, ideas and facts as "meaningful entities" and here there is a tension between recognising that learning is emergent and an epistemology which implies that facts are distinct entities, given a universal character. We can only speculate as to how the focus on concepts as mental representations developed in history, but there appear to be traces of Platonic archetypes in which Ideal forms reside somewhere beyond the material world. In a complex and material frame, concepts can no longer be seen as relating to some other realm, but nor can they be seen as primary to brain or to behaviour. There are many aspects of our brain function which we are not conscious of, and there is some evidence that we only become conscious of decisions after our brains have made them (Soon, et al., 2013). But whilst we might do without 'concepts' at all, it is evident that conscious mental processes do exist.

In this thesis we will only go as far as proposing that cognition is emergent from brain, body and context, and that models which rely upon 'concepts' are brought into question by both complexity and materialism. Considerable work is required to overcome reliance upon 'conceptual understanding' in education and replace it with an account of how learning involves brains, bodies and the context of classrooms.

7.2.5 Concepts and Patterns

In Chapter 5 we considered how pupils learn from context, and there concluded that patterns of behaviour and patterns of association are reproduced in classrooms. Thus, in any attempt to challenge 'concepts' we must also consider these patterns within the social world.

It is clear that mental processes are linked to our shared understandings. People have internal monologues which rely upon language, and those linguistic forms are learned from the world around us. Furthermore, our imaginations draw upon experience[83]. If cognition is related to shared understandings (as well as brains, bodies and context), then this includes the unique

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[83] For example, the relationship between fiction and social understanding has long been acknowledged (Inglis, 1938).

but repeated patterns of behaviour and association that exist within the social realm (see Chapter 5).

To account for these patterns, let us reconsider the example that 'blue-green fireworks contain copper'. In the terminology used within this thesis (see Glossary), an individual pupil may have an 'understanding' of this association. This understanding has a basis in the neural networks of that pupil; it is not an autonomous mental image. When the pupil expresses this association through speech or a diagram, we would here label that as a 'model', because it has a material existence beyond brain and body. The model may affect other people, for example a teacher may respond to the words/diagram. However, 'blue-green fireworks contain copper' is a statement of association that is repeated across the world. In this sense it is a 'pattern' and we have said that patterns are repeated but different. In this case, the association may be related to vastly different fireworks, or expressed in different languages, media etc. The association between blue-green fireworks and copper is a pattern which is manifest in a multitude of models and understandings. Within a materialist frame therefore we are able to leave behind the connotations that concepts exist within an autonomous mental world and that concepts are universal or reside in some other realm.

As was noted in subsection 7.2.2, the conceptual change literature struggles to define 'misconceptions', and we might tentatively suggest that this is because 'concepts' are being conceived of as being beyond the material world. A pupil may 'have the concept' that blue-green fireworks contain copper but still 'have the misconception' that copper metal itself is blue-green. Only in a theoretical frame which aspires to universal ideas which are correct (the acquisition of 'facts') do we need to separate out concepts and misconceptions. In a complex and material frame we see that each individual has a unique understanding born of their past experience, and the models they present emerge within specific contexts. Our shared understanding comes about through the repeated but different forms, behaviours and associations within the material world. Recognising these patterns as such removes the need for concepts as universal mental entities which are acquired during learning. Yet, reference to concepts is so engrained in the way we model learning that is it difficult to 'conceive of' education without it.

Across Section 7.2 we have shown how learning involves brains and bodies engaging with material contexts, including the different but repeated patterns of abstract forms, behaviour and association which make up the human sphere. In so doing we have seen how a materialist frame places 'concepts' in contention: how they cannot be viewed as independent from brains, bodies, contexts or the different yet repeated patterns which constitute social understandings.

At the beginning of this section we highlighted the focus on “conceptual understanding” within the current national curricula for England (DfE, 2013a; 2013b). In the next section we will explore how contemporary curricula characterising learning. This will allow us to show further how a complex and materialist frame challenges existing models of learning as the acquisition of concepts.

7.3 Learning as Contextual

7.3.1 Representational and Presentational Curricula

Having argued that 'conceptual understanding' is an outmoded way of considering cognition, we will here relate this further to processes of education. We have already seen that learning is not a simple, linear process (Section 7.1) and that we cannot assume the primacy of a mental world, autonomous from brain, behaviour and context. The view of learning as the acquisition of concepts is thus brought into question (Section 7.2). However, we are reminded that learning and education are not the same things: education involves intention on the part of educators (Osberg & Biesta, 2008). Therefore we should question not just how concepts relate to learning but also how they relate to education. In order to consider how complex materialism furthers this argument we will draw upon Osberg's critique of schooling as representational (Osberg, 2005; Osberg & Biesta, 2004, 2007; Osberg, Biesta & Cilliers, 2008).

Mollenhauer (1983) argues that in the sixteenth and seventeenth centuries, children were first separated from the world they were to learn about. Since that time, curricula have been developed which are aimed at providing children with the knowledge that they will require for their adult lives. Education in most Western societies is concerned with the representation of the 'real world' in a way that allows students to learn about that world 'as it is' (Osberg & Biesta, 2004). Osberg, Biesta & Cilliers describe this as a 'spatial epistemology' in which there is a correspondence between the world and knowledge of it. However, they go further in showing that not only the representation of a knowable world is brought into question by complexity thinking but also 'presentational' educational practices. These are practices which allow that pupils learn about the world by interaction with it, or which aim at a 'cultural apprenticeship' as well as a traditional knowledge base. Learners are not vessels which can be filled up by experience in the real world but they shape the world as they interact with it.

> "a 'complexity based' understanding of knowledge helps us towards an 'emergentist' epistemology in which 'the world' and our 'knowledge' of it are part of the same complex system (rather than being two separate complex systems, which we somehow need to get into alignment)." (Osberg, Biesta & Cilliers, 2008, p. 223)

Subject content therefore emerges from the particular educational context in which it is found. Osberg, Biesta & Cilliers advocate:

> "schooling as a practice which makes possible a dynamic, self-renewing and creative engagement with 'content' or 'curriculum' by means of which school-goers are able to respond, and hence bring forth new worlds." (Osberg, Biesta & Cilliers, 2008, p. 225)

They argue for "emergent curricula" in which the specifics of what should be engaged with emerges through participation and context. This is subtly different from interacting with a world which is 'presented' to pupils.

Before considering how a materialist position furthers this argument, we must evaluate the characterisation of contemporary curricula that Osberg and her colleagues develop. Osberg, Biesta & Cilliers recognise exceptions to simple representation in forms of progressive education. However, they are not clear as to how we should situate the development of skills as part of curricula. Take the example of the recently replaced science curriculum (QCA, 2007), which aims for a broad 'scientific literacy' and promotes critical evaluation of scientific information in contemporary media[84]. Simons & Olssen (2010) suggest that employability has become a key concern over the last two decades, and discourses around the 'competency' of the future workforce. The aspiration of 'scientific literacy' can be read in these terms. Whilst some aspects of curricula are not simply representational therefore, they still rely upon a projection of what will be needed in later life.

We should also relate representational curricula to distinctions made between intended, planned, enacted, assessed, and learned curricula (Porter, 2004; Kurz, et al., 2010). Osberg, Biesta & Cilliers' argument seems to be against representation within *intended* curricula whereas many teachers are aware that learning in school is not confined to what is intended, seeing their role within the holistic development of a young person. Although this softens the edges of the argument it does not deal a knockout blow however. Enacted curricula and schooling more generally are emergent, but this does not detract from their representational/presentational framing.

7.3.2 Emergent Curricula

The position developed within this thesis supports the rejection of representational or presentational curricula on the grounds that learning is contextual, but also that we can no longer see facts, skills and concepts as entities which exist beyond the material world and can

[84] The new 2014 National Curriculum for Science (DfE, 2013a) reduces the scope for critical skills and returns to more prescriptive statements of knowledge, highlighting the continual relevance of Osberg's argument.

be transmitted or transferred. This begs the question as to what an emergentist curriculum would entail though:

> "Osberg & Biesta (2008, 2010) outline a form of emergentist curriculum… Such an emergentist curriculum is not possible in the current English system as external factors to the classroom, such as examinations and an imposed curriculum document ensure at least a degree of enculturation and goal-orientated activity" (Wood & Butt, 2014, p16)

We have already argued against forms of control and assessment based upon 'effectiveness' (Section 7.1). Thus we will look past the current, practical difficulties to consideration of what emergentist curricula might look like in principle, and how they could be evaluated. Osberg & Biesta (2007) are clear that:

> "an emergentist conception of meaning is not sufficient to release education from the logic of socialization/enculturation. Because the emergence of meaning cannot be separated from the emergence of human subjectivity we see that in trying to produce a certain kind of subject educators are still trying to reproduce a particular meaning (or set of meanings) which they believe is 'good' or 'right' or 'proper'." (Osberg & Biesta, 2007, pp. 319-320)

Whilst they recognise that enculturation cannot be escaped, Osberg & Biesta (2007) argue that the issue is with pre-planned enculturation, aimed at developing a *particular type* of person. Instead, if human subjectivity is seen as emergent then "the classroom must be a space of difference, of otherness, a 'public' or 'worldly space'" (Osberg & Biesta, 2008, p. 324). In relation to the epistemology of schools, they suggest that:

> "This emergentist understanding of knowledge, so we believe, comes close to key insights developed by Derrida, under the label of "deconstruction" which he defines as "the experience of the impossible"" (Osberg & Biesta, 2007, p. 44)

We touched upon Biesta's (1998, 2001) relation of 'otherness' to Derrida's work earlier, and highlighted the issues with it in relation to ethical action in classrooms (see 2.2.6 and 3.2.7). Without rehearsing these arguments here, the issue is in conceiving of this 'other'. Osberg & Biesta (2007) advocate allowing for the unforeseeable, which sidesteps the metaphysical issues of 'experiencing the impossible'. However on this practical level we are still left without a clear way forward in allowing for the unknown.

Furthermore, there is a risk of throwing the baby out with the bathwater. We are to assume that Osberg, Biesta & Cilliers do not wish to do away with all contemporary models in favour of a classroom in which meaning is completely freeform. Osborne (1996) argues that we cannot expect pupils to rediscover the structure of the atom; we must accept schooling as an 'apprenticeship' in contemporary theories and practices which have been hard won over history. Within the confines of a subject discipline there will be 'correct' answers in relation to the solving of an equation, the number of wives Henry VIII had or the form of a Spanish phrase. It is in the situating of these 'facts' within a dynamic worldview that complexity thinking concerns itself. Whilst we rejected the simplistic model of "nested" complex systems that Davis & Sumara (2006) propose, we can uphold their contention that curriculum structures and fields (such as mathematics) themselves develop over time (see 2.2.2). The issue at hand is that we cannot see our curriculum structures as representational of the fields they are related to, or even assume that traditional school subjects are necessarily useful to pupils (divided into English, mathematics, geography etc.).

This thesis provides a different way of looking at the issue. In Chapter 5 we discussed patterns of behaviour and patterns of association which are recognised, reproduced and manipulated. In this light we can see curricula as the specification and encoding of the patterns which are to be reproduced. However, in a complex materialist frame we see that each instance of a pattern is unique. This places the site of emergence within the 'difference and repetition' of patterns within the classroom. So the enacted curriculum is always emergent, because patterns of behaviour and of association are always unique, contextual and historically contingent.

Curricula are also emergent from the social systems in which they are produced. Whilst their authority may be seen to stem from their relation to the 'real world', it is actually imposed by government, examination boards or schools who determine the patterns which are important. There is perhaps hope in the realisation that curricula are always subverted in their interpretation in context. Within this thesis we can characterise a curriculum as a model. It is embedded within complex social systems and, at best, is a model with empirical referents to the world we are trying to prepare pupils for.

Osberg and her collaborators are certainly right to argue against the assumptions of representational and presentational curricula. However, by characterising curricula as emergent models we are also offered a way forward which does not rely upon what is unknowable. If we adapt Deleuze's ethical position then we can argue that overcoming representational curricula should be about comparing those curricula to our immanent experience of the world they seek to model (see 6.1.4). As with Osberg & Biesta's (2008) position, this would allow curricula which were responsive to an emergent and diverse world. Our curricula are models which will never correspond fully to the world they model.

We can see that the patterns of schooling, encoded in curricula and policy, take on a life of their own. The categorisation of knowledge into school subjects and the inclusion of 'facts', which have long since been rendered irrelevant, are reproduced within the educational system. Beyond curricula we see that behavioural expectations, power relations, forms of assessment, pedagogy and many other aspects of schooling have their own patterns which are reproduced yet develop over time. The patterns of schooling do not necessarily relate to the patterns of the broader world. Without providing any empirical evidence here, we can propose that pupils will be learning from these patterns: they learn how to deal with school. Their experiences lead them to adapt their behaviours such that they give the right response in the right context, but there is no reason to believe this will help them in the future. Whilst the adaptations of their neural systems will be carried into new contexts there is no guarantee that new context will trigger a useful response.

The theoretical position developed in this thesis allows us to reject representational and presentational curricula. However, by providing an account of the unique yet repeated patterns of schooling we can situate emergence within classrooms relative to historic patterns of 'knowledge' and behaviour. Thus we can critique not just the epistemology of schooling but the patterns of educational practice more broadly.

7.4 Chapter Conclusion

This chapter has shown how complex materialism challenges existing accounts of learning. However, we have also furthered the utility of the position by showing how it allows us to conceive of emergence in a more concrete way than existing views from complexity do.

We have contrasted emergence to discourses of prediction and control in 'effective' classrooms (Section 7.1). Rather than relying upon a general account of learning as emergent however, we explained that each individual pupil will bring with them a neural network conditioned by their past experiences. Thus, learning will be sensitive to these histories as well as to context. Furthermore, a materialist position highlights the deficiency of comparisons between what a teacher intends and what actually takes place. Teacher intention and the objectives they present are a dynamic part of the classroom system. We also saw that statistical analysis is not up to the task of reducing classrooms to linear causal mechanisms. What is required is an acceptance of the unique nature of classrooms and the learning that takes place within them.

The dynamics of learning were also contrasted to accounts of learning as the acquisition of concepts (Section 7.2). We tentatively related concepts to dualist epistemologies in which ideas are separate from brains and bodies and considered how Piaget and Bruner situate abstract thoughts as belonging to a different category to sensorimotor actions. Drawing upon Chapter 4 we challenged this separation of learning from brains and bodies, but also from the contexts in which people learn. Therefore, we suggested that issues within conceptual change literature stem from the implication that concepts and misconceptions have an autonomous existence, and an epistemology of comparing them to truths which reside beyond the material realm. We showed how using the language deployed in this thesis of understandings, models and patterns we are able to account for learning as a material process.

However, learning is not the same as education. In Section 7.3 we took up the challenge posed by Osberg, Biesta & Cilliers of considering emergent curricula. This thesis supports the rejection of curricula as representations of the real world and instead advocates curricula as emergent within social systems themselves. However, a materialist position, and the model of learning within this thesis, provides a more specific account of emergence in relation to curricula[85]. Emergence is situated in the brains and symbolic representations of people, within the unique contexts of classrooms. This provides an account of emergent curricula which does not rely upon the unknowable.

[85] See subsection 8.1.2 for a concise account of emergence under complex materialism.

By seeing curricula as models of the world, as an encoding of patterns which are deemed important, we promote the critical comparison of these models to what they seek to model: the world beyond school. Yet we also highlighted the fact that patterns of schooling take on a life of their own, and may be premised more on coherence with previous understandings than relation to the broader world.

Overall then we see that complex materialism provides a frame for critiquing existing notions within education. In Chapter 6 we saw that existing characterisations of models are brought into question and here we have challenged existing notions of effectiveness, concepts and representational curricula. However complex materialism also provides an alternative picture of classroom learning, one in which the uniqueness of each context is to be engaged with.

8 Conclusions and Evaluation

8.0 Chapter Introduction

The two focuses of this thesis were to:

1. Establish an ontological and epistemological basis for the application of complexity theory to classroom learning.

2. Evaluate the implications of this theoretical position in understanding classroom learning.

The position of complex materialism has been defined in order to meet the first focus. This was developed across Chapters 3, 4 and 5 and is summarised in Section 8.1 below. The second focus was resolved in Chapters 6 and 7 where the implications of complex materialism for considering classrooms and considering learning were exemplified. In Section 8.2 we will evaluate how the position developed within this thesis relates to the existing positions discussed in Chapter 2. This will show that it might be considered as an original synthesis between concerns across this literature and the materialist ontology which has been adapted from Deleuze. In bringing this to bear on classroom learning we have developed a new frame for seeing learning as material, sensitive to context and historically contingent. However we have only provided a theoretical account of this, drawing upon existing complexity models. In Section 8.3 we will outline how both the theoretical position and description of learning might be furthered.

8.1 The Position Developed

8.1.1 Complex Materialism

In situating learning within complex social systems we can no longer support the separation of mind from the material world. Assuming we believe in a real world, and we must, then any attempt to separate mind and matter is unable to account for how our understandings are constantly adapting through the physical stimuli that our brains receive. Complexity theory puts in motion both the material world and our understandings and in so doing forces us to break the implication that there is a simple relationship between the two. We have shown that the only way to resolve the relationship between the world and our understandings of it is to see the latter as every bit as material as the former. It is absurd to assign our thoughts and ideas to some supernatural realm, to afford them a privileged position in the world or to believe that they are preconditioned by universal categories[86]. This thesis offers a more elegant solution in that our understandings, like everything else, have a material basis.

In light of complexity theory, materialism does not equate to reductionism however. Learning within classrooms is emergent from the material world but we can never fully describe how. Complexity theory tells us that the finest detail, stemming from context or history, may influence a system. We have evolved neural networks which allow us to adapt to experiences and thus carry that learning into new situations. This characterises learning as the adaptation of neural networks to experience, which challenges views of learning as the development of accurate representations of the world 'as it is'. Neither is learning the discerning of simple causal links which exist in the world; it is the recognition of different events as similar enough to be considered a pattern. In this way the human brain is able to deal with patterns across vastly different temporal and spatial scales; we recognise patterns and associations between heterogeneous elements of classrooms, be they facial expressions, position in the room, body language, words, mathematical symbols, images, sounds, equipment, feelings and anything else we can name. When these are seen to all have a material basis, and our understandings to be a material response to them, the full complexity of human learning becomes apparent.

Whilst the above provides an account of how learning is material and allows us to situate understandings within complex social systems, it is only part of the story in relation to human learning. We learn from each other, both directly and through the symbolic and linguistic systems that have evolved within our cultures. By characterising learning as the adaptation of brain and behaviour to patterns amongst heterogeneous elements of classrooms, we have

[86] These positions relate to Plato, Hegel and Kant respectively.

already paved the way for considering how we develop shared understandings. Learning from the natural world, from each other and from the world of symbolic artefacts can all be characterised as a fundamentally material process. The key to seeing how we have shared understandings comes from recognising that the patterns of behaviour and association which we learn from are not exactly the same each time they occur. Processes of replication mean that behaviour, symbolic forms (such as words and phrases) and associations are reproduced in new contexts. However, these are deemed as repetitions in the eye of the beholder. In this way the human sphere is characterised by “difference and repetition” (Deleuze, 2004a [1968]).

We are thus able to distinguish individual ‘understandings’ from ‘models’. Models may include the understandings of individuals but also the words, mathematics, computer programs, art forms and other symbolic artefacts which exist beyond brains and behaviour. Models, like understandings, have a material basis and may (or may not) go on to influence the social systems that contain them. This sheds new light on our models in general, but in this thesis we have focused on the implications of this for understanding classrooms. Our models of classrooms are linked to those classrooms not through some supernatural connection, but through the processes of their genesis and through our evaluating them as useful.

Complex materialism has at its heart the ontological claim that the world is composed of a single, complex system of material. Through considering processes of neural and behavioural adaptation this is combined with an epistemological position which sees learning as the adaptation of understandings and models which have a material basis. These models and understandings are not related to another realm of truth, universal ideas or *a priori* categories of reality, they are constantly adapting in relation to the natural and social world in which they exist. The ontological and epistemological positions cannot be separated within a monist, materialist frame which sees learning as emergent from the interaction of matter. The combination of an account of the world as fundamentally material and an account of how learning can be seen as a process of adaptation within classrooms allows us to align complexity theory with learning.

8.1.2 The Emergence of Learning

Throughout this thesis we have been critical of claims that learning is emergent which do not provide a specific account of how this is the case, or which rely upon the language of complexity alone (see 1.3, 2.2.2 and 2.3.3). It is therefore appropriate to here state how this thesis considers learning to be emergent.

A pupil in a classroom has a brain and body which reflects both their biological inheritance and the experiences they have had thus far in life. This is manifest in a neural network which has a macroscopic structure similar to all other humans, yet the exact configuration and structure of neurons will be unique. To build on an example we used in Chapter 5, take the hypothetical situation that a teacher asks pupils to match together pieces of paper which each have the name of a metal on, with further pieces of paper showing firework plumes of different colours. Although the exact image of the blue-green firework might be new, the prior experience of the pupil means that her brain has a response to that image: she recognises it as a blue-green firework. So too the word 'copper' is recognisable despite being a unique instance of ink on paper. Let us suppose that the pupil has not yet experienced the association between blue-green fireworks and copper metal, but that during the task one of her friends puts the picture of the blue-green firework and the word 'copper' together. The pupil now experiences the image and the word together, and this experience has the potential to stimulate a response in the pupil's neural networks which we might label as learning. Through unique instances of patterns which a pupil has encountered before (firework plumes and the word copper), the pupils is able to learn from the material of the classroom.

However, we have said that there is only potential for the pupil to learn from this event. Contemporary models of neural processes are not detailed enough to conclude whether neural adaptation occurs to every stimulus, so we learn from all our experiences, or whether processes of selective plasticity, reinforcement and pathway degradation ('forgetting') mean that adaptation is more 'selective' (see Chapter 4). However we have identified a range of influences which will affect how learning takes place (detailed across Chapters 4 and 5). Focusing on the individual pupil we can see that her unique history will influence her response. This includes her goals and motivations, how hungry she is, and ongoing processes of consolidation, but also her prior understanding of copper and fireworks. All of these are manifest in the neural responses already developed to these patterns. This historic contingency is furthermore situated in a specific context and we have drawn attention to how relationships, empathy, mimicry, coordinated motion, position in the room, transactive memory in groups, praise and the equipment and environment of the classroom might influence the pupil. So whether the pupil is engaged in the task about fireworks, has confidence in her friend or values the praise of the teacher could all influence learning.

The interaction of historic contingency and specific context make emergence ever likely though the nonlinear interaction of a myriad of influences in any moment. Yet this can be accommodated within a materialist frame and supported through models of neural adaptation. As well as providing a specific account of emergence, this thesis suggests that we have shared understanding because of the repeated patterns of symbolic and abstract forms, of behaviour and of associations within the social sphere. Thus we have given an account of both difference and repetition.

The above is a hypothetical model, and we have argued that the details of a specific situation will never be fully recognised by a model. However, here we must also recall that this thesis contains no primary empirical evidence, and that it draws upon models of neural and behavioural adaptation which are themselves tentative. Nevertheless, the account of emergence above is itself emergent from this doctoral study and should be compared to existing models (see 6.1.4). In the next section we will do just that by comparing it to the existing accounts of human understanding within the complexity literature. This will also allow us to evaluate the originality of complex materialism and the above model of emergence.

8.2 Originality and Relation to Existing Work

8.2.1 Relation to Complexity Science

In order to evaluate the originality and contribution of this thesis it is fruitful to consider here how the position developed relates to the existing positions discussed in Chapter 2. Table 2, a summary of these positions and associated issues, is reproduced here for ease of reference:

Table 2 – Overview of Complexity Approaches and Theoretical Issues

Complexity Approach	***Features***	***Theoretical Issues***
Complexity Science	• Generation of models using scientific processes. • Often claims to be 'pragmatic'.	• Inherits positivist terminology such as 'universal laws'. • Models often lack empirical referents. • Theoretical basis of models often neglected.
Post-structuralist Complexity Thinking	• Rejection of representation. • Blurring of epistemology and ontology as mind/matter seen as same system. • Recognition that understandings are transient.	• Rejection of empirical evidence removes criteria for assessing models. • Unable to resolve how people act in complex systems with only partial understandings.
Complex Realism	• Asserts the causal influence of macroscopic social entities, e.g. a classroom, school, society. • Asserts importance of empirical referents.	• Inherits separation of mind and matter. • Aspires to 'more realistic' models which is problematic in complex systems.
Complex Responsive Processes	• Mind situated as outside brain. • Accounts for shared understanding.	• Equating minds and the social is untenable. • Cannot account for learning which is not social.

In Section 2.1 we considered approaches to social complexity which we labelled as 'scientific' in that they utilise mathematical, computational and experimental approaches which inherit a positivist epistemology and/or a reductionist approach (see 2.1.1). There we saw a range of approaches to situating understanding: characterising humans as agents who undertake mechanistic processes; as following 'universal' scaling laws; as operating within networks of relations. Models of learning within contemporary scientific literature are yet to be of utility to educationalists because of these simplistic accounts of learning. Through contrasting them to a broader view of how learning emerges from individual histories and specific contexts the reduction within existing models becomes apparent.

We argued that it is simplistic to say that scientists are unaware of the limitations of their models. However scientists need to more fully consider how they are situating human understanding within their models, as well as how they situate models themselves. The latter requires a greater explanation of how models relate to the phenomena they model. We noted that there is an 'internal consistency' of models which support other models and often the original phenomenon is not referred to at all (See 2.1.5). Even when sophisticated models of action are developed in relation to empirical evidence (e.g. Hall et al.'s (2011) model of baboon behaviour), these models at best generate hypotheses around processes and influences within social settings.

This thesis does not provide advances in the practice of modelling but instead allows us to better situate models within a coherent theoretical frame. Models are emergent from complex social systems, such as science, and may go on to influence those systems. In Chapter 6 we developed this characterisation of models to show that they can be linked to the phenomena they model on three counts. Firstly, in relation to social settings we suggested that people tend to recreate the situations they expect to find, for example classrooms come to look similar because people draw on models of how classrooms should be. In considering this in relation to science we can tentatively suggest that models are developed through the understandings of the scientists involved, so may recreate what is expected. Secondly, through processes of their genesis, models can abstract some aspect of a phenomenon. We have used the example of a photograph replicating the pattern of light from a scene, but an agent-based model might abstract from an observed course of action; a statistical law might abstract a relation between data points; a network might abstract perceived links between people. The third way a model may be linked to a phenomenon is through judgement, after its genesis, that it repeats some important pattern (see subsection 6.1.3).

Seeing models as material entities challenges a distinction between ontology and epistemology because processes of knowing become processes of emergence from the material world. In relation to scientific approaches to social complexity we see that processes of genesis are important and this will allow us to uphold the call from complex realists that empirical evidence is important (we shall discuss this shortly in 8.2.3). It also highlights the importance of scientists recognising the fields in which they operate and the inheritance of techniques and existing models on which they draw. Evaluating models becomes not about how accurate it is in relation to the 'real' phenomenon but about utility, which is necessarily a normative concern.

In relation to models of classrooms we developed a number of further insights from this account of modelling as the emergence of material abstractions (see Section 6.2). Firstly, there is no need to focus on a specific 'level' of analysis. In Chapters 4 and 5 we described how humans are able to respond to heterogeneous patterns across a broad range of temporal and spatial scales. Scientists tend to focus on a single unit of analysis and we suggested that this may be due to a focus on causal links rather than inductive patterns (see 6.2.2). A second implication of seeing models as complex and material is that the notion of 'boundaries' is outmoded; it does not adequately recognise the 'gaps in between' the patterns being delineated. Thirdly, we argued that models may contain parameters which have no immediate empirical correlate. We have seen that every model is an abstraction and as such does not evolve as the original phenomenon does. Importance should be placed on recreating patterns of interest and not on an unachievable quest for accurate representation.

Complex materialism therefore provides a basis for reconsidering scientific models of social phenomena: it recognises the potential utility of these models whilst highlighting the need to elucidate processes of their genesis and evaluation. Seeing models as material also 'opens up' processes of modelling classrooms, allowing consideration of heterogeneous elements and modelling parameters by overcoming concern for boundaries and specific levels of causal analysis. We have also suggested that comparing models to actual phenomena is an ethical imperative (see 6.1.4).

8.2.2 Relation to Post-structuralist Complexity Thinking

Complex materialism is able to uphold many of the concerns of authors who we have labelled as post-structuralist. As was expounded in Section 2.2, the linking of complexity with post-structuralism is concerned with recognising the provisional and dynamic nature of our understandings, as well as challenging a view of representation as a simple correspondence between a phenomenon and our understandings of it. As was discussed above, if we see understandings and models as emergent then there can be no simple relationship between thoughts, language, symbolic abstractions and the broader world. In Chapter 4 we showed how our understandings and responses are distributed across our neural systems and embodied in our actions. This challenges the view that we can accurately represent the complex world. Furthermore, in Chapter 5 we extended this argument by showing that learning from other people and from symbolic language means that each of us has a view of the world conditioned by our unique experiences, rather than through approaching a complete representation of the world.

Despite complementarity between some aspects of post-structuralist complexity and the position developed in this thesis, there are also sites of disagreement. The differences were discussed in subsection 3.2.7 and we shall summarise them here only insofar as to allow evaluation of originality. In short, we argued that by drawing on Derrida's deconstruction, authors such as Cilliers also inherit an unresolved metaphysical issue. Derrida takes on Hegel's dialectical philosophy by showing that binary opposites cannot be resolved and meaning is constantly deferred (see 2.2.6). In drawing on deconstruction Cilliers inherits this issue, despite developing a much more concrete account of how meaning is distributed across networks. Meaning is constantly deferred within a network so we are forced to accept that such networks are interrogated in real time in some way. Cilliers recognises this issue and talks of boundaries in making sense of statements, as well as recognising what is outside of these boundaries: what is 'other'. We argued in subsection 2.2.4 that in practice this concern for boundaries does not escape the issue of how we make decisions in real time. We cannot accept what Derrida (1990, p. 967) calls the "madness" of making a just decision.

These issues are resolved within this thesis by adapting Deleuze's monist position. The key to characterising meaning is to reject the supernatural connotations of relations within 'systems of meaning' and instead see meaning as emerging from the specifics of a moment. In a position which sees the world as a single, complex and material system we see that each instance of a repeated pattern is unique. Deleuze argues that this "difference and repetition" explains why we associate similar events with a specific label. This position is developed and related to specific processes over Chapters 4, 5 and 6. Perhaps ironically therefore, drawing initially on Cilliers' model of distributed representation within neural networks we have eventually rejected his application of a neural picture to human symbolic systems. Our brains use networks to discern and respond to patterns but there are no physical connections between words in a language or concepts in a system of thought. We have suggested that there are processes of replication which facilitate the repetition of similar patterns within the social world but we should not see these as connected metaphysically. This thesis offers a more concrete and specific explanation of why we should reject assumptions of representation and see human understandings as tentative, dynamic and partial.

8.2.3 Relation to Complex Realism

Complex realists situate themselves as occupying a 'middle ground' between post-structuralist accounts of dynamic understanding and scientific reductionism (see 2.3.1). As such, many of the comparisons made above between these positions and complex materialism apply to our analysis of complex realism. Here however we will consider the primary concern of reinstating the reality of social entities, as well as the failure of complex realists to situate their own models.

As discussed in relation to complexity science above, within this thesis we have upheld the call for models to have material correlates in the phenomena they model. In attempting to reclaim the importance of empirical evidence however, complex realists go too far in accepting the separation of their models from the world they model. In seeking to reclaim scientific and social scientific processes they allow positivist assumptions back in by not adequately accounting for how models are themselves within social systems. In subsection 2.3.4 we suggested that this is to do with an insistence on separating ontology from epistemology. Whilst asserting that the world consists of complex systems, complex realists see our theory and models as "discursive with" that world (Byrne & Callaghan, 2014, p. 110). Complex realism attempts to maintain that we can have an objective understanding of the complex social world, yet fails to recognise that all understandings are partial and dynamic, and should be situated *within* complex social systems.

By asserting that all aspects of social systems should be considered real, Byrne & Callaghan (2014) argue that social entities (e.g. welfare reform or social class) should be seen as having causal influence. As was argued in subsection 6.1.1, this affords these entities causal powers when in fact they are abstractions. A policy may influence classroom practice but this is through the myriad understandings of individual people and the symbolic language they deploy. For example, in saying that a change to a curriculum benefits working class boys, a complex realist may claim a causal link between the curriculum and a social entity: working class boys. As we saw in Section 7.3, a curriculum is not an autonomous entity in itself but has emergent influence in a multitude of specific settings; the aggregate of all working class boys is not an autonomous entity, but an abstraction based upon some criteria. The simple causal influence is in our model, not in the broader world.

Complex realists do get very close to situating their models as within complex social systems: Allen & Boulton (2011) characterise models as different from the real world; Byrne & Callaghan draw on notions of social fields which condition agency (see 5.1.3). However they don't quite get there; they don't discuss how their own models are conditioned by the social world as well as the phenomena they seek to investigate. Complex materialism provides a way of upholding the need for empirical evidence whilst also recognising models as emergent and incomplete. It forces complex realists to rethink the implication that our models can be 'more realistic' and instead recognise their models as abstractions which must be evaluated as such.

8.2.4 Relation to Social Construction

We have argued that both scientists and complex realists (who are primarily social scientists) separate the material world from our understandings and models of it. Furthermore, Cilliers does not give sufficient account of how the social and material worlds are related. Social constructionist positions, which we exemplified with Stacey's (2001, 2003a, 2003b, 2005) work, offer a solution to this by equating the social world with the understandings of individuals. This position has particular relevance to education, firstly because it can be linked to social constructivist accounts of learning and secondly because it is able to account for why we have shared understandings.

In Section 2.4 we showed that Stacey's model of 'complex responsive processes' suffers from an inability to account for the world beyond social interaction. If we accept that there is a material world then we must also accept variations in time and space which influence how social understandings develop. Put simply, once you introduce a dynamic, nonlinear account of social construction you are forced to confront the material world. The interactions between this material world and a shared social mind cannot be resolved. Furthermore, social construction relies upon Hegelian dialectics and this is to be overcome (see 2.4.3). As was noted in subsection 3.2.6, a materialist position cuts through this by recognising the social as having a material basis, so mind and matter are part of the same systems and can interact.

As well as being unable to reconcile dynamics and 'social mind', social construction is not able to account for how we learn from the world around us, be it through exploratory learning with new objects and equipment, or in learning from the words, symbols and patterns of the social world (see Section 5.3). However, for all its issues the social constructionist position does account for why we have shared understandings within social systems. It is thus important to show how complex materialism is able to recover this notion of shared understanding but also account for how we learn from the broader world. The narrative of this ran through the middle part of the thesis: subsection 3.2.6 showed how mind and matter should be considered as part of the same system; Chapter 4 then provided a process by which we are able to recognise patterns within heterogeneous elements of classrooms; Chapter 5 built on this by showing how we are able to recognise, respond to and manipulate patterns of behaviour and association which exist in society. This is not to afford a supernatural quality to these patterns, they all have a material basis, but it is to recognise that shared understandings are important in how we learn (see 5.3.3).

Complex materialism sees shared understandings as emergent from repeated patterns which are manifest in specific situations. In recovering these concerns from social constructionist positions it is able to account for learning in the social sphere as well as the broader material world.

8.2.5 Originality

In relating complex materialism to existing accounts of social complexity above, we see that it provides a coherent account of how understandings and models can be situated within complex social systems. However, we can also see that the position developed is a synthesis of existing concerns and its originality should be evaluated as such: an original synthesis. Prominent in this synthesis is the post-structuralist concern for the tentative and incomplete nature of our understandings, and view of our symbolic and linguistic systems[87] as dynamic. The concern from complex realism for empirical evidence and importance of engaging with the real world is also supported, as is the constructionist concern for shared understandings. However, we have not allowed the differences between these positions to be swept aside through appeal to analogy or a general view of complexity: specific processes have been described.

Another key element of this thesis is the inspiration it takes from Deleuze's metaphysical system. As was noted in subsection 3.1.1, the interpretation of Deleuze's work within this thesis would be unpalatable to many Deleuze scholars. However, in several respects the thesis also leaves Deleuze's notions behind. By seeking a concrete process by which we recognise 'repeated but different' patterns we focused contemporary literature around the complexity of brain and behaviour. This provided more tangible processes for Deleuze's claims and also removed reliance upon the 'virtual differences': both in accounting for human agency and in how our models replicate aspects of phenomena (see 4.2.3 and 6.1.2 respectively).

Furthermore, in developing our notion of patterns of behaviour and associations in Chapter 5 we have taken Deleuze's empirical relationship between experience and our concepts and subjected it to several other aspects of the complexity literature: models of mimicry, group

[87] Following Deleuze's position, we may further move away from the connotation that a 'system' is interconnected in a way which affords 'relations' an autonomous existence.

learning, and neural coordination; discussions of sensitivity to context and history; distinctions between learning and education. We have certainly not engaged with even a majority of Deleuze's thought and therefore, whilst Deleuze's work is pivotal to this thesis, it is the interpretation and synthesis of it with complexity models which provides originality.

As well as synthesising concerns from different aspects of contemporary literature with an interpretation of Deleuze's work, this thesis is original in bringing that all to bear on classroom learning. The application of complexity theory to classroom learning is certainly not unique and we have drawn on several accounts within this thesis. However, the combination of complexity theory, Deleuze's metaphysics and a focus on classroom learning is new. Of course, combining three seemingly disparate areas of study is likely to create novelty, but the contribution to educational discourses lies in the capacity of complex materialism to offer a critical perspective. In the introduction to this thesis we cautioned that we are far from "a new science of education" (subsection 1.3.3). However, through the lens of complex materialism we have provided grounds for challenging simplistic notions of learning as a linear process, as the acquisition of conceptual understandings and as the representation of the world beyond curricula (see Chapter 7). We have also highlighted the importance of both teachers and researchers recognising their understandings of classrooms as abstraction (Chapter 6).

The originality of this thesis lies in a synthesis of existing positions to develop a coherent basis for bringing complexity to bear on classroom learning, and as such has advantages over existing accounts of social complexity.

8.2.6 Contribution

Whilst the above discussion of originality relates to existing accounts of social complexity, we will here situate this thesis within broader educational discourses. In Chapter 1 we outlined both the appeal of complexity theory and the issues which have resulted in its remaining marginal. The appeal of complexity is an ability to move beyond simple cause and effect and to recognise the dynamic, sensitive and specific nature of classrooms. It also has the capacity to challenge the contemporary focus upon 'evidence based teaching', not through denying the utility of evidence, but by situating it within the complex systems we inhabit. We proposed that complexity remains marginal within education because of the difficulties in developing a coherent theoretical framework which is able to capture the unique nature of classrooms, and because of the specific issues of accounting for human understandings. Humans have partial understandings within complex systems but we cannot escape those understandings in conceiving of complexity.

As stated from the outset, the contribution of this thesis lies in firstly expounding these challenges and secondly providing a solution to them. Complex materialism provides a basis for situating learning within complex social systems and this has extended to both understanding *within* classrooms, but also our understanding and models *of* classrooms. Indeed it allows us to see why these issues cannot be separated: our understandings are always part of the world and are constantly evolving with it.

Characterising social complexity as we have within this thesis therefore provides an argument for moving out of the shadow of the scientific disciplines in which complexity was first discussed. Complexity theory necessitates holding a mirror up to processes of understanding and modelling, as well as a rethinking of epistemology and ontology. Fields such as education yield greater experience of engaging with human agency, social entities, politics and ethics, and these are essential parts of this rethinking. By situating modelling within the material world, and providing a specific account of how understanding emerges, it is hoped that this thesis might be a first step in moving out of the shadow. We must cast off appeal to analogy and the restricted processes of traditional science and recognise the potential of complexity as a discourse of learning and education.

Under the umbrella of this broader hope for educational discourses, this thesis has provided a model of learning as emergent within the specific contexts and specific histories of classrooms, and it has grounded this within a coherent materialist ontology. In drawing on contemporary neuroscience, computational models and studies of behaviour and development, we must recognise that the arguments of this thesis are historically situated. However, by showing how we might challenge contemporary ideas of effectiveness, conceptual understanding and representation we have shown how this thesis has direct relevance to contemporary discourses. Therefore, by providing a specific account of learning as complex, a coherent theoretical basis for this account, and situating it relevant to contemporary discourses, we have laid a foundation on which to build new understandings of classroom learning.

However, there is still plenty to be done, and we will now turn to considering what has been omitted from this thesis and what the next steps might be.

8.3 Omissions and Areas for Further Development

8.3.1 Boundaries and Omissions

In subsection 6.2.3 we argued that the notion of boundaries implies a spatial or temporal region which misses the 'gaps in between' models as abstractions. If we indulge that this document is an abstraction of a doctoral study, and in turn that study is an abstraction of the fields of complexity and education, then it would be inconsistent to attempt to here define what has not been included in this thesis. However, in the development of this thesis a number of conscious decisions were made as to what would be excluded as the thesis was edited down from a considerably larger body of writing. As such a few autobiographical notes may be helpful in describing omissions from the final thesis. These were in the specific models of human agency utilised, in the methodological approaches to complexity considered and the sociological and learning theories touched upon.

The background of the author as a physicist goes some way to explaining why the models of human agency explored in Section 2.1 could be classified as originating primarily within physics and why the models of neural adaptation considered in Chapter 4 stem from network analysis. However Maturana & Verala's (1980) more 'biological' description of complexity is of potential relevance to this thesis, stemming from descriptions of 'autopioesis': self-maintenance of a system. Maturana & Verala focused upon the adaptation of the nervous system to experience and, like Cilliers, argued against representation within the nervous system. As such parallels may be drawn to the models developed in this thesis. However, their model is one of environmental pressures causing an autopioetic response within the nervous system such that the real world is not represented at all: an extreme form of social constructivism. As well as the difficulty in resolving the world outside of the brain, Maturana & Verala focus on cellular processes within the brain, and it was felt that this did not adequately account for the electrical patterns which form the basis of much of contemporary neuroscience. Whilst there are undoubtedly points of similarity therefore, Maturana & Verala's work might be considered as an alternative to the models explored in Chapter 4, but relates to an epistemological position which is not supported in a materialist frame.

Another notable figure is Juarrero (1999) who develops an account of action as determined by dynamic constraints and utilises a range of complexity science notions to support the role of narrative in understanding the historically determined and context-specific nature of these constraints. This thesis has instead focused upon describing the processes by which understandings emerge in a theoretical capacity. No doubt Juarrero's autobiographical approach would be useful to both researchers and teachers considering specific classrooms. Within the doctoral study, a great deal of time was spent understanding methodological issues around agent-based models, network analyses, case study, action research, dynamic equation models and autobiographical accounts. Discussion of this has been reduced in order to allow clearer focus upon a theoretical basis for complexity in classrooms.

As well as models of adaptation and detail of methodological issues, specific theories of social learning have been downplayed or omitted from the final thesis. Although we have related complex materialism to Bourdieu's "social fields" (see 5.1.3), we noted that there are a range of sociological theories which might account for human agency within complex systems, for example Actor Network Theory (Latour, 2005; Blake; 2004) or Social Cognitive Theory (Bandura, 1999). Of particular interest is Deleuze & Guattari's (2004b [1980]) notion of 'assemblages' as loose organisations of heterogeneous elements, although they do not develop this fully. DeLanda (2006a, 2006b) espouses the capacity of 'assemblage theory' to link levels of reality. However, his interpretation is haunted by a sense of hierarchy and misses the interdependence of different temporal and spatial scales (see 6.2.2). DeLanda's interpretation of assemblages also misses a sense in which these hodgepodges of people, symbols and objects are self-sustaining, coevolve and have a role in normativity[88]. In considering learning within classrooms this thesis has necessarily focused on how individuals respond to patterns within the social world (Chapter 5). However, this does not preclude the utility of considering social entities and, indeed, it may provide a specific material basis for such consideration.

As well as social theories, we have encountered learning theories, particularly those of Piaget, Vygotsky, Bruner and Skinner in several places and noted the links made to complexity in the existing literature[89]. However we have not developed a full relationship between complex materialism and learning theories in contemporary use. The relation of both existing social theories and contemporary learning theories to complex materialism was viewed as secondary to elucidating the theoretical position itself. Developing these relationships may be considered as an area for further study. We will now turn to two additional areas in which this thesis might be further developed.

[88] Assemblages may also be tentatively linked to Foucault's notion of 'apparatus' (Simons & Olssen, 2010).

[89] The fullest linking of complexity to Piaget and Bruner's work is in subsection 7.2.1, however Piaget is mentioned in no fewer than nine subsections and Vygotsky and Skinner are cited on multiple occasions also.

8.3.2 The Language of Representation and Response

An area of development worth detailed consideration is the tension within this thesis between the situating of models as themselves material entities and the language of representation and 'response' which originates from the accounts of brain, behaviour and social interaction. We must be absolutely clear that when we consider the understandings of individuals, or models more broadly, we are not characterising them as fixed responses, which emerged *from* experience: a one-way street. Furthermore, in Chapter 3 we highlighted the ethical necessity of comparing models with the phenomena they pertain to, but this should not be seen as a simple feedback loop in which a model emerges and then comes to influence a future situation.

There is much already within the thesis that undermines the characterisation of understandings and models as simply emergent responses. We have seen that brain, body and behaviour are linked in a complex way such that understandings, as manifest in brains, cannot be divorced from action (see 4.2.2). This built upon Freeman's (2000) account of reafference in relation to brain function: the continual searching for information within the environment according to the endogenously defined goals of the individual (see 4.1.3). Such goals highlight the importance of understandings in resulting actions. Furthermore, drawing upon Gallesse & Lakoff (2005), we have considered how multimodality within brain function means that we are constantly 'imagining' the future (see 7.2.3).

Nevertheless, the characterisation of learning within this thesis has predominantly been one of learning *from*. This stems from the scientific conceptualisation of time as the stepping through of processes which underpins key models within this thesis, for example, Cilliers' account of adapting of neural structure (see Chapter 4). Although we will not fully overcome the language of response here, we will here highlight ways of doing so.

In subsection 2.1.5 we considered Dewey's 'transactional theory of knowing' and how it challenges a separation of mind from world (Biesta, 2011; Olssen, 2011). Dewey's position provides a way of characterising experience as part of the situation in which it occurs:

> "An experience is always what it is because of a transaction taking place between an individual and what, at the time, constitutes his environment, whether the latter consists of persons with whom he is taking about some topic or event, the subject talked about also being part of the situation; or the toys he is playing with; the book he is reading (in which the environing conditions at the time may be England or ancient Greece or an imaginary region); or the materials of an experiment he is performing. The environment,

> in other words, is whatever conditions interact with personal needs, desires, purposes, and capacities to create the experience which is had." (Dewey, 1938a, p. 41-42)

Dewey includes imaginary places, desires and purposes in this interaction, in echo of the flat ontology which we have supported within this thesis. Furthermore, experience cannot be seen as a progression of temporal frames:

> "the principle of continuity of experience means that every experience both takes up something from those which have gone before and modifies in some way the quality of those which come after." (Dewey, 1938a, p. 27)

Dewey and Bergson corresponded (e.g. Bergson 1999) and their sensibilities around experience and time are commensurate, as exemplified by Dewey's description of the 'feeling qualities' of primary experience, prior to sensations:

> "Primary experience is both the starting point and the end point if inquiry; inquiry is critical, reflective, knowledge yielding process; and this reflective process is what Dewey means by secondary experience." (Skilbeck, 1970, p. 14).

Thus Dewey's theory of inquiry starts with qualitative experience from which knowledge is generated through reflection. However, Dewey situates personal needs, desires, purposes and capacities as constantly interacting with the environment which is experienced. Skilbeck (1970, p. 14) suggests that "Like Kant, he believed the mind plays an active part in the determinations of the character of its own experiences". However, consideration of Dewey's body of work shows that he does not deal in universals as Kant does.

> "The child does not have to be drilled into the fact that snow is cold and ice is good to skate on; his experience is connected with those things, they mean something to him, and if the appropriate stimulus presents itself with any kind of frequency, anything approaching frequency, the experience, the meaning, the truth of it carries itself along in his mind and becomes the center for the accretion of other experiences." (Dewey, 1966, pp. 313-314)

Here we see that experience is conditioned by the 'meaning' of the stimulus for the child. In Chapter 4 we referred to the 'internal mechanisms' within the brain which condition the searching for and adaptation to stimulus. Dewey's work surpasses this thesis in considering at length the motivations, habits and desires of pupils and how they develop, albeit on a psychological rather than neurological basis. These develop through interaction with a world that they are part of, without reducing this to simple causality. This makes Dewey's language of 'transactions' appropriate in relation to the theoretical position developed within this thesis.

A further resonance between this thesis and Dewey's is apparent when we see that the latter "agrees with classic teaching, according to which perception, apprehension, lays hold of form, not matter." (Dewey, 1938a, p. 240). Biosvert's (1988) analysis suggests that Dewey favours learning from 'forms' in nature and this is worthwhile considering in relation to our characterisation of patterns within this thesis. Dewey is clear that forms and relations are not universals:

> "The relation is thus invariant. It is eternal, not in the sense of enduring throughout time, or being everlasting like an Aristolean species or Netwontian substance, but in the sense that an operation as a relation which is grasped in thought is independent of the instances in which it is overtly exemplified, although its meaning is found only in the *possibility* of these actualizations." (Dewey, 1984, p. 130)

However, the consideration of actualizations also invokes Deleuze's notion of the *event*, which we touched upon in subsection 3.2.3[90]. Semetsky (2006, 2008) at length shows how "For Deleuze, as for Dewey, thinking depends on our coordinates in space-time." (Semetsky, 2006, p. 81). Therefore, whilst maintaining that Dewey's framing of transactional learning provides a way out of the language of response, we will here sketch out how Deleuze's position furthers this.

In relation to the quote from Dewey above, we have seen already that Deleuze seeks to escape the dualist/dialectical trappings of 'possibilities' (see 3.2.5). In this sense, Deleuze's form of materialism is more fully rendered than Dewey's because it recognises the dualist/dialectical implication of possibilities. In defining an "interaction" Dewey (1938a, pp. 38-39) argues that any experience is an interplay of "objective and internal conditions" and throughout his work describes how desires, efforts and habits contribute to the 'growth' of the child. Dewey is clear that inquiry involves the constant reconstruction and reorganisation of our past experiences as well as anticipation of the future, the latter being changed by the very act of reflection. Nevertheless, it is the individual which is growing, and there remains a trace of what Hollins (1977, p. 59) calls Dewey's "Hegelian upbringing". There is an implicitly dialectical relationship between the objective and the internal in Dewey's work.

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[90] We might also relate Dewey's 'operation' to Bhaskar's (2008 [1974]) 'mechanism' which is real whether actualised or not (see 2.3.2).

In the terminology deployed within this thesis, Dewey focuses upon how the *understandings* of individuals develop in interaction with their environment. Drawing on Deleuze however allows us to see beyond the individual to the *models* which exist within the broader material world. Recall from subsection 3.2.3 that Deleuze replaces essence with event (Smith & Protevi 2015) and that this owes a debt to Bergson's duration. However, Bergson's duration and Dewey's transactions both focus upon the individual, whereas to Deleuze individual thought is part of the event. To Deleuze (2005 [1995], p. 31) "The immanent event is actualized in a state of things and of the lived that make it happen. The plane of immanence is itself actualized in an object and a subject to which it attributes itself". To Deleuze, events can only ever be actualized. This takes us beyond the individual and situates thought as part of the ever changing material world.

Both Byrant (2011) and Patton (1997) use the example of battles to explain actualization in Deleuze's work: the weapons, people and other material entities involved constitute the *pure event* but the concept of the battle itself becomes one of the actors in the situation and guides the actions and analyses of those involved. Deleuze (2004b [1969]) talks of the 'counter-actualization' of events into dynamic concepts which then escape the spatio-temporal circumstances of the initial event and persist in time. The battle of Waterloo persists as a concept long after the events of 1815 and might still inform the actions of a military strategist, a scholar or a conversationalist. Deleuze denotes influence of the concept on a new state of affairs as 're-actualization'.

> "Events are complex in the sense that they are always composed of other events, however minimal or momentary. They are structured both internally and by their relations to other events." (Patton, 1997, para16)

However, given our discussion of models (primarily in Chapter 3) we might add that the relations that Patton talks of should not be given an autonomous existence; relations within a model are 'counter-actualizations' in Deleuze's terms.

Deleuze's notion of event provides a way of escaping the simplistic language of response by recognising that human thought systems are part of a continuously emergent material world in which the pure event, the state of affairs 'as it is' can never be approached. The 'scientific' characterisation of time as a sequence of moments must be left behind in recognising that both the past and the future are integrated into the actualized events of the present. Dewey's recognition that we are part of the world and that learning should be seen as transactional is furthered when we recognise that those transactions are not just with the natural world but are also with the 'image of thought' which permeates the human sphere. Models both exist beyond and include human understandings, all of which form a complex material.

By drawing on accounts from the neurological, cognitive and behavioural sciences this thesis has taken on the characterisation of learning as the response to the environment. As Rajchman (2005, p. 20) notes, Deleuze was concerned with reintroducing movement into thought at a time when accounts from neuroscience threatened to reduce thought. This thesis goes some way to showing how contemporary neuroscience and Deleuze's thought might reinforce each other, but what is required is a furthering of the language used to describe how we learn as part of a complex and material world.

8.3.2 Comparing Models to Classrooms

In furthering the language used to describe learning as within the material world, we would further our account of how models interact with the broader world in which they exist. Drawing upon our arguments in subsection 6.1.4, we can also propose that the models within this thesis are best advanced by comparison to actual classrooms. Whilst the details of how this takes place will emerge from context, we can here propose four aspects of this thesis which might be advanced by such a comparison.

Firstly, we have developed an account of learning as the interaction of brain, behaviour and context. This is sufficiently broad to allow almost any classroom event to be viewed in these terms and therefore needs to be related to how specific learning emerges from a particular classroom at a particular moment. Only through repeated exposure to incidences of learning in classrooms can the specifics of such a model be developed and tested. We have also proposed that learning is sensitive to context and history and this may be supported in relation to seeing how similar activities and settings may result in very different learning.

Secondly, in Chapter 5 we proposed that we learn through interaction with repeated but different patterns within the social world: linguistic and symbolic patterns; patterns of behaviour; patterns of association. This way of viewing learning can only be developed through describing patterns within real classrooms.

Thirdly, Chapter 6 suggested a number of ways that we should reconsider how we characterise models. We suggested that a broader range of heterogeneous elements could be included once we escape concerns for boundaries and specific levels of analysis, as well as the inclusion of modelling parameters without specific correlates. There is a tension between this 'opening up' of modelling processes and the need to constantly relate models to real classrooms. This tension needs further exploration which can only come through the development of such models in practice.

Fourthly the comparison of models to actual classrooms is advocated on the basis of an ethical position which is currently underdeveloped. We have supported Cilliers (2004) contention that modelling is a necessarily ethical process and drawn on an interpretation of Deleuze's suggestion that we are "immanent" to the systems we model (see 6.1.3). This needs to be developed further in terms of how we can compare models and the systems they model. We consider models to be material entities which include neural networks within the brain, so this is not a straightforward question. However we must also be aware that any description of classroom learning has the potential to do harm, including the descriptions within this thesis. As this thesis is read and hopefully the patterns within it spread, we must therefore recall that:

> "A theory does not totalise; it is an instrument for multiplication and it also multiplies itself." (Deleuze & Foucault, 1972)

Glossary of Key Terms

Throughout this thesis a number of key words are used in specific ways. Definitions are given here in order to aid the reader:

Bifurcation	The point at which a system may develop in two or more possible ways. This is usually represented as different pathways on a phase space diagram.
Complexity	Complexity refers to systems in which multiple influences interact with each other and with the environment such that causal processes cannot be discerned.
Complexity Theory	Complexity theory is defined within this thesis as the set of all models which describe complexity (see 1.3.1).
Complex Realism	Complex Realism is the position that the world is real and consists of complex systems (see 2.3).
Concept	Whilst the term concept is used in its every day usage as 'an abstract idea' in the first part of this thesis, this definition is deliberately put in contention in Section 7.2, where the autonomy of ideas and mental representation is challenged.
Constructionism	The co-development of social understandings through interaction.
Constructivism	How an individual develops a view of the world through interaction with it and other people. Distinguished from constructionism in focusing on individuals.
Dynamic	Beyond just denoting constant change, dynamic refers to variables altering on temporal and spatial scales such that the same event may result in different effects if it occurs in a different time or place (see 1.2.4).
Emergence	The development of a structure, form, understanding or model within a complex system such that the causal mechanisms cannot be discerned. See 1.2.3 for history of the term.
Epistemology	Philosophical discussion of how humans understand the world.
Historically Contingent	The system contains elements or has structures that have developed within its history and which may come to influence future development.

Materialism	The ontological position that the world consists of a single substance at the fundamental level. Matter, energy and forces are emergent from this substance. String theory offers a contemporary model of this (see 3.1.1).
Model	Models become defined as material entities which consist of the understandings of individuals but also symbolic forms: words, mathematics, computer programs, media and art forms. These are related to the phenomenon they model in both the way they are developed and in the way they are evaluated (see Chapter 6).
Multiplicity	A set of multiple instances of a similar experience which become associated with a particular label or behaviour. Deleuze (2004a [1968]) use this notion to show how understanding emerges from qualitative experience.
Nonlinear	Originally from the mathematical field of nonlinear dynamics this is given a broader definition in this thesis as denoting the presence of multiple influences such that simple causal processes cannot be discerned (see 1.2.1 and 1.2.4)
Ontology	Philosophical discussion of what exists.
Phase Transition	When a system undertakes a qualitative transformation. For example ice becoming water above zero degrees Celsius (a transition point).
Phase Space	A multidimensional space which is used to represent a number of variables (dimensions) of a system. For example, a five dimensional space might represent three dimensions of physical space, time and temperature.
Positivism	The epistemological position that humans can discern fundamental truths about the world.
Post-structuralism	A school of thought originating in the mid twentieth century which questions the simple correspondence between our linguistic and symbolic systems and the world they relate to.
Pragmatism	Often used by scientists in the sense of 'what is practical' and/or to sidestep philosophical issues. Also a specific school of thought originating in the late nineteenth century which considers the utility of thought.

Representation	Different forms of representation are discussed within this thesis. Simple representation refers to the assumption that there is simple relationship between the world and our understandings or models of it. In contrast, distributed representation refers to the structure of a network having no clear relation to the structure of a phenomenon and yet having a conditioned response to it.
Understanding	In Chapter 2 the term understandings is utilised as sufficiently broad to allow consideration of the way human thought and action are characterised within the existing literature; pertaining to both thought *within* complex systems and notions *of* complex systems. From Chapter 4 onwards the term is used to denote the emergent response of an individual's embodied neural system at a particular moment.

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