COMPLEX ADAPTIVE SYSTEM BEHAVIOURS IN SMALL GROUP INTERACTION: A YEAR 4 CLASSROOM CASE STUDY OF LEARNING AS 'EMERGENCE'.

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ABSTRACT

Depictions of classroom teaching and learning in politics, policy and media tend to be over simplified and mechanistic. Insights from research on classroom learning draw largely on the ‘what works’ paradigm, which presents learning as directly caused by teaching. ‘What works’ approaches dominate education discourse, despite their failure to capture the complex, interactive dynamics and ‘messy’ topography of classrooms. This study sought to generate novel insights about small group and classroom learning by acknowledging, rather than ignoring, their complexity.

Using complexity thinking (a heuristic drawn from complexity theory) as a conceptual frame, this thesis presents findings from original classroom-based research exploring the emergence of learning in small group activity. Mixed method data, including social network analysis, pupil self-reporting, interviews and observation, were collected during one week in a year four classroom of a UK primary school. Data integration revealed interesting and otherwise tacit insights about antecedents of group and individual learning. Findings suggest that learning has emergent qualities and that individuals exert influence on collective learning due to emergent system dynamics, including social status, personality and knowledge states. Contributions to knowledge include insights about the interplay of top-down and bottom-up organising principles in small group and classroom systems. The thesis also evaluated the usefulness of complexity thinking as an analytical frame for understanding group learning, with mixed conclusions.

The study has the potential to offer novel contemporary interpretations of classroom teaching and learning from a systems perspective.

‘One shouldn’t complicate things for the pleasure of complicating, but one should also never simplify or pretend to be sure of such simplicity where there is none. If things were simple, word would have gotten around...’

Jacques Derrida (1988, p.119)

Table of Contents

1.0 Introduction

1.1 Introduction to the field of study and research aims

Support for the view that classroom learning and teaching are not straightforward processes is widespread. As Davis and Sumara (2006) point out, any teacher will attest to the unpredictability of learners' responses to teaching. Eisner (1985:104) described teaching as 'an inordinately complex affair' and others, (Tripp, 1993; Woods, 1990; Clark and Yinger, 1987) frame teachers' roles in terms of managing uncertainty and problematising unpredictability. Shulman (2004, p.504) puts it in categorical terms, 'teaching . . . is perhaps the most complex, most challenging, and most demanding, subtle, nuanced and frightening activity that our species ever invented'. Descriptions of the elicitation and facilitation of learning by teachers themselves (Gipps, McCallum, and Brown 1999; Prawat, 1992) also acknowledge the unpredictable nature of learning. As Alexander, Shallert and Reynolds (2009, p.176) point out, 'One cannot begin to understand the true nature of human learning without embracing its interactional complexity.' The case for learning and teaching being far from straight forward affairs is also captured succinctly by Schön, who described teachers' work as operating in the 'swampy lowlands' of everyday life. For him, 'the problems of real-world practice do not present themselves to practitioners as well-formed structures. Indeed, they tend not to present themselves as problems at all but as messy indeterminate situations' (1987, p.4). In acknowledgment of assertions such as these, this study aimed to elicit insights about primary classroom learning and its emergence in small group interactions.

Notwithstanding such depictions of the complex nature of learning and teaching, a popular portrayal in policy and public discourse presents teaching and learning as simple, linear, causal and mechanistic processes, reflecting a technical rationalist view of the profession (Furlong, 2000; Caine and Caine, 1997; Schön, 1983). In this conception, teachers apply instrumental solutions to address well-formed problems. Discourse and national agendas concerning teaching, learning, pupil progress, curriculum, standards and teacher professional development are typically driven by this input-output conception. In the dominant policy discourse, 'Outstanding' teaching is narrowly defined as the meticulous planning of lessons to meet specific, predetermined objectives (Eaude, 2012) and despite years of reform, the language of policy (see the Teachers' Standards - DfE, 2011 - for example) still partially depicts a transmission and absorption notion of teaching and learning. Tessellating policies of national testing, league tables, school inspection and teacher competency descriptors firmly position teachers as the lynchpins (Clarke, 2012) of pupil progress with the consequence that they are routinely held accountable for a phenomenon (learning) which according to theorists, academics and teachers themselves, is only partially within their control. Television, online and print media routinely present narratives about school exam results, league tables and 'best' or 'worst' performing schools (Kirk, 2020; Pattinson, 2020; Adams, 2019; BBC, 2019), with performance usually cast as solely a function of 'good' or 'poor' teaching (House, 2018; Tait, 2018; Phillips, 2010). This leads to the popular notion that if teaching is 'Outstanding' learning will (or should) be too. The human tendency to seek simple, causal explanations and simple solutions to complex phenomena which feeds on such narratives is discussed in Chapter Two.

The pupil end of any learning and teaching relationship is no less complex than the teaching end. In any given school cohort 'the persistence of inequities in student achievement' (Sinemma, Aitken, and Meyer, 2017, p.12) speaks to a range of factors influencing learning. These include inherited and environmental predispositions such as cognitive ability, personality, confidence, task commitment and risk-taking tendencies along with home and school ecosystems. Ecological factors such as social dynamics (Sedláček and Šeďova, 2020; Hendrickx *et al.,* 2017), nutrition (Hoyland and Lawton, 2009), mood (Canovi, Kumpulainen and Molinari, 2019) and even classroom temperature (Wargocki, Porras-Salazar and Contreras-Espinoza, 2019) may also play a part. Research from several paradigms offer insights into learner factors and their effects on learning. For example, Bronfenbrenner's (1979) ecological systems theory presents a framework for describing community and environmental influences on individuals' development. Research into the emergence of gifts and talents in school age learners (Renzulli, 1986; Tannenbaum, 1983) have highlighted common elements which typically correlate with high performance, including general cognitive ability, environment, personality, self-confidence and chance. Numerous studies from the field of psychology (Gardiner and Jackson, 2015; Komarraju *et al.*, 2011; Ntalianis, 2010; Chamorro-Premuzic and Furnham, 2008) illustrate how personality influences readiness to learn and learning outcomes. Studies of class emotion and mood (Canovi, Kumpulainen, and Molinari, 2019; Molinari and Canovi, 2016; Stone and Thompson, 2014) reveal how pupil interactions, on/off-task behaviours and learning can be influenced by interpersonal features including regulation, negotiation and resistance. Despite wide-ranging acknowledgement across multiple disciplines that learning is influenced by a complex array of mutually influential factors (those mentioned above and many not mentioned e.g., working memory, self-efficacy, parents' education, personal health and cultural expectations to name a few), its depiction in public and policy discourse remains largely characterised by the receiving and remembering of knowledge and the mastery of predetermined skills. This is evidenced most clearly in the way that policy developments in the United Kingdom, and comparable education systems, over the last forty years have striven to routinise teaching (Knight, 2017; Menter, 2010; Mahony and Hextall, 2000). This study sits within this educational and policy landscape.

I have previously argued (Knight, 2017) there is a need for more accurate depictions of teachers' work and its relationship to pupils' learning, my hope is that this study will contribute towards this. As Hardman (2010) points out, there has been a failure of simple causal explanations to adequately account for the complexities of school and classroom learning. Drawing on data from episodes of small group classroom activity, this study responds to the suggestion from Dalke *et al.,* (2007) that new arguments are needed from which novel insights might emerge about the nature of classroom learning.

1.2 Theoretical framing: A brief introduction to complexity theory

A less reductionist, more accurate depiction of classroom learning and teaching will necessarily acknowledge their complexity. The theoretical framing of the study, and its methodology, are informed by complexity theory. As a relatively novel theoretical lens in education, it warrants an introduction.

Complexity theory (an umbrella term applied to analysis of a range of dynamic, non-linear systems) is a transdisciplinary conceptual framework through which to view change within systems. Emerging originally from disciplines including computer science, cybernetics, chaos theory and the natural sciences (see e.g. Lewin, 2000; Holland 1995; Kelly, 1994), complexity theory has been used since the 1950s, and more recently in the social sciences, as a tool for understanding systems containing multiple agents (in this study pupils, teachers, ideas, environment) whose adaptation, development or change is resistant to explanation using traditional scientific method, or as Newell (2008, p.5) puts it, 'phenomena resistant to reductionist analysis.' Complexity theory breaks with linear, causal or deterministic explanatory frameworks (Morin, 2006), rejecting a version of reality in which 'a knowledge of inputs is adequate to predict outputs' (Davis and Sumara, 2006, p.11). In the social sciences, complexity theory has been applied to organisational behaviour, healthcare, city planning and education, and used to analyse how people operate within groups and how change occurs in organisations. Complexity theory distinguishes between systems which are merely complicated, such as clocks or engines, and systems which are complex. Complicated systems have many moving, interacting parts which behave in centralised, repetitive, predictable and linear ways. They remain consistent over time. In contrast, complex systems display less predictable, bottom-up, emergent and non-linear behaviours, because the elements constantly and mutually affect one another (Holland, 1998). Central to the behaviour of complex systems (and therefore to this study) are the concepts of emergence and self-organisation. Complex systems are said have emergent properties, meaning that change occurs from the bottom upwards. Patterns of coherent, aggregate behaviours form across the system due local, autonomous decision-making, rather than centralised control; this is referred to self-organisation. Self-organisation is the *what* and emergence the *how.* Because complex systems change, they are often referred to as complex adaptive systems (CAS). This research analysed learning in one primary classroom through a CAS lens to attempt to determine any ways, and the extent to which, learning can be said to have emergent qualities.

1.3 Research questions

The focus of this study was the ‘emergence’ of learning and associated complex behaviours in a primary classroom. The principal aim was to employ a complexity framing to develop non-reductionist insights about learning and teaching. The research questions are stated later in this chapter; the wider research objectives were:

1. To gain insights into the emergent qualities of learning,
2. To illuminate aspects of learning which cannot be easily described within a mechanistic, linear or causal framework, or are not attributable to direct instruction,
3. To trial, discover and theorise conditions in which classroom learning may ‘emerge’,

4. To draw conclusions about how teaching may be configured to encourage learning as 'emergence'

Since applying complexity to the context of classroom learning is relatively novel, the study also evaluates the credibility of complexity as a framework for conceptualising classroom learning. The research was novel in the following ways:

1. Complexity-sensitive educational research is still in relative infancy.
2. The research is predicated on the assumption that no single theoretical depiction of learning, however well-established, is sufficiently comprehensive, sovereign or adequate to capture the pluriform nature of learning in classrooms.
3. As well as framing the data analysis, a CAS lens also informed the methodology, meaning that the 'what' and the 'how' were inter-related.

The research questions were:

1. To what extent can learning be said to have 'emerged' within small group classroom activity?
2. What are the characteristics of 'emergent' learning?
3. What conditions encourage 'emergent' learning?
4. How useful is a Complex Adaptive System (CAS) framing for analysing primary classroom small group learning?

1.4 Justification for the study

1.4.1 Personal and professional rationale

My career in education has spanned almost twenty-five years, first as a primary school teacher, as a school senior leader and now as a senior lecturer in initial teacher education (ITE). Throughout my eleven years as a primary class teacher, I became increasingly aware of a divergence between portrayals and conceptions of the teaching-learning nexus in policy and public discourse on the one hand, and my own experience as a teacher on the other. The dominant conception of learning and its relationship to teaching in the former arenas has always been, and remains, one in which pupil outputs are seen as exclusively a function of teacher inputs. Political, news media and public discourse are all built around this seemingly fixed structural axis which generates the inevitable conclusion that if a child is not meeting age related expectations in their attainment, poor teaching is the likely cause. Reasons for the persistence of this narrative are discussed in Chapter Two. I was a successful teacher, however my experience of planning for, teaching and assessing learning ran somewhat counter to this narrative. It has always been evident that the quality and appropriateness of teaching is a significant determinant of learning outcomes. However, I also noticed regularly that different individuals, groups and cohorts of children could respond very differently to the same teaching, that what worked one day was not always successful the next, that children sometimes grasped a concept before I had taught it, that children sometimes finally understood an concept weeks after it had been taught, or that children could understand something rather differently from me or the way I had conveyed it. These tendencies in the relationship between teaching and learning were not confined to my classroom or my school. According to Alexander, Shallert and Reynolds (2009) they are the experience of everyone engaged in the business of supporting and facilitating human learning.

For politicians, policy makers, the media, the wider public and many parents, teaching and learning seem to exist in a tightly mechanistic and causal framework in which the ‘right’ teaching will produce the ‘right’ learning. For teachers, this causal framework is more stochastically constructed. Having taught through an era of growing curricular prescription, accountability and surveillance (1998 – 2009), one of the consequences of this dichotomy between my own and external conceptions of teaching and learning was the sense that I was held publicly accountable for a phenomenon (learning) over which I had only partial control.

In my current role as a teacher educator, I observe undergraduate and post-graduate students grappling with the same complex nature of learning whilst on school placements. My time spent observing and coaching student teachers, teaching about teaching and learning and assessing students' professional development has reinforced my earlier reasoning that teaching does not directly cause learning, but that, as Alexander, Shallert and Reynolds (2009, p.180) put it 'learners are influenced by, and at the same time push back from, change, control and create the environment in which learning is situated'. This disconnect between how I experience teaching and learning, and how it has been commonly portrayed has led me to sit with professional discomfort similar to that described by McNiff (2006). The personal and professional rationale motivating this research is a desire to contribute towards a portrayal of teaching and learning which acknowledges their complexity.

1.4.2 Theoretical framing: More on complexity and complexity thinking (CT)

Complexity theory has been employed as a lens through which to analyse systems in and of education for a little under three decades now examining, among other things, curriculum (Osberg and Biesta, 2008; Doll, 2008, 2002, 1993), educational research (Radford, 2008; Haggis, 2008; Kuhn, 2008; Davis and Sumara, 2006) purposes of schooling (Osberg, Biesta and Cilliers, 2008), educational change (Mason, 2008; 2009) and the philosophy of education (Morrison, 2008). Empirical studies have been undertaken into areas of education including school interventions (Wetzels, Steenbeek and van Geert. 2016), non-linear modelling for - education systems (White and Levin, 2016; Guevara, Posch, and Zúñiga, 2014) and agent-based studies at system, school and classroom levels (Ingram and Brooks, 2018; Kosta, Koch and Thompsen Primo, 2016; Blikstein, Abrahamson and Wilenski, 2008). A small number of studies have examined classrooms, focussing on similarities between classroom systems and complexity characteristics, comparing pupil interactivity with the non-linear, ensemble agent behaviour characteristic of complex systems (Hardman, 2015; Sullivan, 2009; Newell, 2008; Fong, 2006). My justification for framing primary classroom small group learning as complex draws on these accounts which suggest that complexity has useful applications in the analysis of classrooms and classroom learning.

Complex classroom behaviours have been framed differently by different researchers however and as discussed in Chapter Three, there is currently no agreed-upon definition or model of a complex classroom system. Despite this obvious drawback, a small, but growing, number of researchers have analysed systems of education, schools, curriculum and classrooms using a complexity lens, revealing its potential to offer novel insights. In its current form complexity can best be described as a heuristic (Kershner and McQuillan, 2016). The main justification for employing this heuristic comes from the well-established notion that learning is a 'timeworn, slow and gradual fits-and-starts kind of process' (Hattie, 2009, p.2) and teaching an 'inordinately complex affair' (Eisner, 1985, p.104). As Hardman (2010) attests, complexity's appeal lies in its ability to depict classrooms more as teachers tend to experience them.

Applied to the primary classroom learning, complexity theory has the potential to illuminate aspects of the teaching-learning nexus which traditional, linear, causal thinking may not. This research conceptualised a case study Key Stage 2 primary classroom as a complex adaptive system (CAS) and learning in groups as a complex, emergent phenomenon which occurs within (and beyond) that system. Viewing the classroom as a CAS offered scope for examining how changes in learning 'emerge' when the system itself is not fully subject to deterministic causal frameworks, which is arguably the case to varying degrees in all classrooms. This is not to say that there is no causality or predictability to classroom learning, but even in the most tightly controlled classrooms causality does not operate with strict linear predictability. Adopting a CAS framework however, also brought its challenges, not least the necessity for non-linear thinking. In order to fully exploit the potential of CAS analysis a researcher needs to replace linear with non-linear thinking, being cognisant of and sensitive to complex behaviours which more typical, linear framings may not reveal. As is the convention when applying complexity theory to social contexts, I employ the concept 'complexity thinking' (CT) to indicate that whilst a primary classroom can only be partially likened to other CAS (e.g., weather systems, swarming insects or the immune system), my analytical and methodological approaches are informed by the complexity theory heuristic.

The most significant voices concerned with CT and education (Davis, Sumara, Hardman, Mason, Morrison, Biesta) agree that caution should be exercised when attempting to conceive of school classrooms as complex or equating emergence with learning. Analogies taken from complexity science on radically emergent systems, such as insect swarms, suggest that a classroom organised along similar principles would maximise knowledge sharing between pupils, have little by way of top-down leadership, prioritise individual self-interest and investigate questions to which neither pupils nor teachers know the answer. By necessity, this is not how most classrooms operate, a point discussed at length in Chapters Three and Eight. Whilst complexity offers 'intriguing and generative metaphor(s)' for the classroom system (Newell 2008, p.16), there are obvious limitations to such analogies. Despite some reservations however, there is agreement among those who have examined classroom learning through a CT lens (Davis, Newell, Hardman and Sullivan in particular) that instruction alone does not cause learning and that there are, as yet unearthed insights about learning which CT may elicit. By characterising learning as emergent, the study was particularly concerned with:

- Pupils noticing and identifying critical incidents in their learning, making realisations and connecting existing and new knowledge through bottom up, rather than top down processes.
- Observing how small-group classroom organisational structures influence the emergence of learning.
- How group dynamics and pupil interactions interact with degrees of autonomy and constraint within the classroom system to occasion learning.
- Conditions which give rise to the emergence of learning.
- Identifying feedbacks, signals and recursions in the networked causalities of group learning contexts.

1.4.3 Limitations and points of difference with current and previous studies

Previous studies into interactive classroom learning have tended to focus on dialogic teacher-pupil interaction (Alexander, 2018, 2017) genres of peer-peer talk (Mercer, 2000) and thinking skills (Wegerif, 2011) all of which examine the dialogic moment and its influence on reasoning and understanding. In many existing studies into pupil interaction and learning, the issue is framed by teaching (or 'the adult'), largely analysing what is overt and tangible from transcripts of classroom dialogue. Conclusions from such framings overlap a great deal and differ only marginally from one another, presenting little by way of hypothesis about underlying dynamics, conditions or what can be learned from 'off-task' interaction. In addition, many previous studies on collaborative and interactive learning have been undertaken in inauthentic settings (Baines, Blatchford, and Chowne, 2007) by isolating individual groups from the main class one at a time and examining learning in pre-structured frameworks. Almost all existing research on interactive learning is also firmly rooted in the 'what works' tradition (whatworksnetwork.org.uk, 2021; Education Endowment Foundation (EEF), 2021; Pellegrini and Vivanet, 2020; Morrison, 2012; Biesta, 2007 - discussed further in Chapters Three and Seven) which sits uncomfortably alongside CT. This study sought to examine the spaces between and beneath pupils' interactive utterances, drawing on multiple data sources across different times and naturalistic contexts in order to throw light upon a broader range of explanations for learning which dialogic transcripts alone do not typically illuminate.

Most complexity framed education discourse has so far been theoretical, highlighting obvious counterpoints between CT and prevailing portrayals and cultures of education. As Koopmans and Stamovlasis (2020) point out, to date almost all writing on the topic has been concerned with theorising education as innately complex, rather than actually researching it. This study aims to meet the challenge of eliciting empirical insights about classroom learning through a CAS lens. One other significant empirical study shares similarities with the present study. Sullivan (2009) investigated aspects of learning in three American high school classrooms (mathematics, English and Jazz music), asking whether the classrooms were CAS in a doctoral thesis entitled 'Emergent Learning: Three Learning Communities as Complex Adaptive Systems'. Apart from the contextual differences between Sullivan's and the present study (secondary not primary, three separate classrooms, not one single classroom, focus on whole class rather than small groups), the key conceptual difference is that Sullivan was asking whether classrooms are CAS; his conclusion was a qualified 'not really', though he acknowledged several examples of complex behaviours. I have also discussed this question (Knight, *in press*), with a broadly similar conclusion that 'it depends' on a range of contextual factors. The present study however, was not asking whether the case study classroom was a CAS, rather it applied a CAS framing (set out in Chapter Three) to elicit insights about learning, asking ‘does learning have emergent qualities and if so, what is emergent learning like and what conditions support it’? My working hypothesis for the study was that learning can emerge bottom-up as a consequence of pupils exercising degrees of local autonomy.

1.5 Methodological framing and research setting

This section will briefly introduce and rationalise the chosen methodology for the study. Byrne and Callaghan (2014, p.57) describe complexity theory as an ‘ontological frame of reference’ which ‘engages with the philosophical foundations of social science.’ My interest in analysing the classroom through a complexity lens originates from my ontological position on the nature of social phenomenon. Complexity’s abandonment of simple, linear, causal explanations of change in human systems aligns with my own long-held view that causes, effects and outcomes of human collective activity are poorly accounted for by such frameworks. I am ontologically a complexivist, believing that authentic understandings of the social world can best be achieved holistically (Phillips, 1976), by resisting temptations to reduce systems to ‘lower order components’ (Byrne, 1998). Congruent with this view, my epistemological position is that the only authentic means by which to come to know the world as I experience it is through interpretation and by avoiding the temptation of simple explanations. This is not to deny the existence of causality, but to acknowledge that causes and their effects in the social sphere are often multiple, networked and tacit, even to forensic exploration.

As CT and complexity-sensitive research in the field of education are quite new, there is no single, recommended methodology. Approaches are constructed less in terms of what they are and more in terms of what they are not (linear, causal or scientific method). My approach was ‘informed by complexivist sensibilities’ (Davis and Sumara, 2006, p.87), meaning that I was vigilant to the complex qualities and characteristics of the classroom, but not overly rigid in borrowing analogies and frameworks from complexity theory. As a conceptual framework CT offers points of reference for my assumptions about the nature of reality, my epistemology, my axiology and my understanding of how learning may occur in primary classrooms. These are discussed further in Chapter Three.

Methodologically, existing educational complexity research has been largely interpretivist to date. I concur with Haggis’ (2008) view, also asserted by Crotty (1998) that interpretivism does not mean anti-quantitative, in fact, complexity research has its roots in statistical modelling. According to Crotty, ruling out quantitative approaches in post-positivist research is ‘far from justified’ (1998, p.15) and Haggis (2008) further asserts that words and numbers should be used ‘in some kind of combination’ (p151). According to Brinkman and Kvale (2005:162), when the object of inquiry is concrete human experience ‘qualitative methods are the most adequate means of knowledge production.’ However, as Cilliers (1998, pp.136-7) points out, complexity ‘forces us to consider strategies from both human and natural science, to incorporate both narratives and mathematics – not to see which is best, but in order to help us explore the advantages and limitation of them.’ This was a mixed methods study with quantitative social network analysis (SNA) employed as a springboard for qualitative analysis of video, interview and observational data. Quantitative and qualitative data were integrated to build learning narratives which document the topographies of learning. The closest methodological match for the research was a mixed method, complexity-sensitive case study.

The setting for the study was a Year 4 class in a two-form entry British primary school. The school was part of a large local Multi-Academy Trust (MAT) and was situated on a large modern housing development serving a predominantly middle-income catchment area on the outer fringes of a British city. The school had ‘Rights Respecting School’ (RSS) status meaning that it met the required standards set out by UNICEF UK, placing the United Nations Convention on the Rights of the Child (UNCRC) at the heart of its ethos (UNICEF, 2021). The school website states that ‘pupil voice and partnership in learning is central to the enriched curriculum we offer’ (School website, 2021). This was particularly relevant to the research because viewing the classroom through a CAS lens meant pupil autonomy and voice were central to the analysis. The school ethos was built around ten research-informed ‘aspects’ which it aspires to have ‘at the core of everything’ it does (School website, 2021). Its openness to research and commitment to developing research informed practices also made this school an ideal setting for this study. The school’s physical layout also made it an appealing prospect as a site for a systems approach to classroom research. The teaching areas were entirely open-plan, with very few walls separating teaching and learning spaces and ‘class zones’ demarked by colour-coded tables and chairs. In theory this invited teachers and pupils to work in more expansive ways, encouraging collaboration and cross-fertilisation between cohorts and classes.

The Research took place over one week during the summer term and was designated as an ‘enrichment week’, during which normal curriculum teaching and learning gave way to the project of designing, testing and making plastic bottle rockets. As part of the research design, pupils worked in small groups and were given greater autonomy over choices and activities relating to the project than they were usually afforded in their everyday curriculum learning. The teacher also took on roles more akin to facilitator than instructor compared with his usual curriculum teaching approaches. A brief overview of the week’s activities is shown in Appendix O. Chapters Three and Four give more details about the research week itself.

1.6 Conclusion

This opening chapter has introduced the research project, its conceptual and methodological framings and justified the research with reference to professional and personal contexts. The following chapter discusses relevant literature, including findings from previous studies into classroom and small group learning and complexity framed classroom research.

2.0 Review of literature

This thesis explores the possibilities of emergence at the nexus of teaching and learning in the context of small group collaboration in a primary school classroom. The research investigated to what extent and in what ways learning can be said to have emerged bottom-up through pupil interaction. This review of literature begins by examining existing ideas about the nature of learning. It then explores seminal and contemporary perspectives on learning in groups, focussing on the nested structures of small groups within whole class contexts. Following this, the focus moves to arguments about the credibility of conceptualising classroom learning through a complex adaptive systems (CAS) lens. Finally, wider discourses, including the phenomenon of simplicity and its influence on perceptions of primary classroom teaching and learning, are discussed.

2.1 The nature of learning

This study's focus on learning as an emergent phenomenon necessitates a brief exploration about what it means for human beings to learn. The aim of this section is to foreground the chapter with a discussion of consensus views on the nature of learning in order to establish points of reference for subsequent discussions about classroom learning.

According to Ewens and Cammack (2019, p.34) learning is 'multi-layered and difficult to pin down in a single definition'. Common to most explanations of learning, however, is the notion that it involves change. From a psychological perspective, Lefrancois (1999, p.41) describes it as 'relatively permanent changes in behaviour or in potential for behaviour that result from experience'. Alexander, Shallert and Reynolds (2009) explain that for humans to be said to have learned, change must have happened, positing that 'there are no current conceptions of learning that do not include the notion of change, either explicitly or implicitly' (2009, p.178). Three corollaries are implicit in this conception of learning. Firstly, that changes can be significant and obvious, or tiny and virtually imperceptible. Secondly, that changes can occur immediately, or over large time scales and thirdly, that change is usually systemic, meaning changes are not isolated to individuals but occur reciprocally within and between learners and their environment. All three assertions are of interest to this study, with its focus on learning as an emergent phenomenon.

If learning is change, it is worth considering what exactly changes. Piaget's main concern was changes in cognitive structures, or schema. He described (1952) how a child's innate drive for equilibrium prompts exploration of the world which disrupts, or changes, that equilibrium as new experiences are accommodated, and cognitive structures altered. This seminal theory presents learning as a self-perturbing (the child seeks out experiences which disrupt its cognitive equilibrium) engine of change, emphasising the inevitability of learning. Vygotsky, whose main concern was the development of higher psychological functions, alluded to change continually, whilst rarely using the term itself. He distinguished between development and learning, arguing (in contradiction of Piaget) that as well as the former driving the latter, the latter also drives the former (Vygotsky, 1978). Vygotsky considered the development of higher psychological functions to be driven by an individual's wider socio-cultural development which 'itself must be understood as a change in the basic original [biological] structure and the development of new structures on its base that are characterised by a new relation of the parts' (1997, p.83). Evident here, and in Piaget's theory, is the idea that change is not sudden and wholesale, but incremental and iterative.

The idea that learning involves gradual additive, deconstructive or reconstructive changes to existing knowledge, mental structures or capabilities is common across other depictions of learning. Bransford, Brown and Cocking (2000) explain learning in terms of transfer from previous experiences and point out that processes of building the new onto the existing are not always smooth, since existing knowledge structures can make it difficult to accommodate new information. When individuals construct mental representations change is required at a conceptual level. Conceptual change, which involves the reforming of underlying mental structures and learning, is often described as generative in that learners select, engage with, mentally organise and integrate information and experiences to form and reform coherent structures (Fiorella and Mayer, 2015). The view of learning as generative has similarities with Guanglu's (2012) contention that the integral functions of speculation and revision of hypotheses in learning make it essentially a recursive process. Similar explanations come from the field of neuroscience, where learning is described as processes of forming and re-forming of synaptic architecture in response to experience. According to Zeithamova *et al.*, (2019) the brain is capable of rapid and flexible adaptation to new knowledge and experiences. This framing aligns with the notion that learning changes can be reliably characterised as organising, reorganising, building on, or otherwise working with, existing structures (synaptic, conceptual, knowledge-based).

Perspectives from neuroscience and cognitive psychology explain changes in terms of adaptations of neural pathways, symbolic representations and habits of mind. However, common to explanations of school learning is the contention that learning requires content or a subject about which changes revolve. Alexander, Shallert and Reynolds (2009, p.181) distinguish between tacit or incidental learning, and conscious or intentional learning, explaining that 'there is always a *what* that is being learned or that is in the process of change'. The 'what' can range from changes in non-cognitive domains such as unconscious habits, conditioned responses or motor development, to higher mental domains such as conscious and effortful grasping complex scientific concepts. Biesta (2009) suggests that when referring to someone as having 'learned' something, a value judgement is being made that the 'what' that has been learned is good and desirable. In this sense, he argues that learning is not a descriptive term, but an evaluative one, implying that educational learning is not just a process of change, but a process of goal-directed change. Biesta (2009) makes an important distinction between incidental or exploratory learning, in which learning may be the consequence of exploration and interaction with peers and environment, and planned curriculum learning. He argues that in the context of education, it is not acceptable to just learn anything, the purpose is for pupils to learn particular things.

In the context of education (and therefore the context of this study) learning is most usefully understood as change in a desired, planned direction. The forming and reforming of structures, whether through exploration or direct instruction, occurs in the interest of some purpose. Curriculum imposes purpose and orientation, channelling permanent and semi-permanent changes towards prescribed goals, what Osberg and Biesta (2008, p.314) refer to as 'purposely shaping the subjectivity of those being educated' and Davis (2008, p.47) less generously, as the 'knowledge' half of the unfortunately entrenched 'knowledge/knower' dichotomy so prevalent in education systems. In the context of education therefore, learning changes take on the characteristics of acquisition or accumulation of predetermined knowledge, skills or understandings. This is qualitatively different from learning in the general sense, as merely any change. This theme is explored further in section 2.3. In the sections which follow, learning, defined as change to prior or existing structures, is discussed in the curriculum orientated, social context of primary school classrooms. Looking firstly at general arguments that learning is constructed through social interaction, then moving on to explore small group work as an organisational vehicle for those interactions.

2.2 Learning as social

Everywhere in the world, wherever organised education exists, children are found learning in together in groups, or classes. The reasons for this are partly philosophical, but largely practical. On the practical side, as mass education followed industrialisation, grouping children into manageable units, mostly on the basis of age, has proven the most efficient long-term means of educating populations. The utility of this approach explains its ubiquity across the world. From a philosophical perspective, the advantages of learning together in groups have been explained, discussed and re-explained innumerable times over the course of the latter 20th and early 21st centuries. Though the language of social constructivism entered the lexicon relatively recently, the underlying concepts, as applied to teaching and learning, began with the socio-cultural movement, and most prominently with Vygotsky and his influential observation that

> 'Any function in the child's cultural development appears on stage twice, on two planes. First it appears on the social plane, then on the psychological, first among people as an interpsychical category and then within the child as an intrapsychical category.' (Vygotsky, 1978, p.57)

This seminal idea birthed the concept of shared constructions of meaning by articulating the value of, and dynamics by which, 'external and internal transitions within classroom social processes' changed the mental apparatus of the developing child. (Kirshner and Kellogg, 2009, p.48). As such, the central premise of socio-constructivism is that learning is essentially a collective activity. This premise is neatly summed up by Pritchard and Woollard (2010, p.35)

> '[…] as human learners, we depend upon social interaction with those around us for the stimulus, challenge and shared activity which work to promote thinking,

> engagement with ideas and activities and serve to allow for intellectual growth, including growth in knowledge and understanding.'

The principle that shared activity creates conditions which promote thinking and learning changes is based on the observation that humans tend to present one another with challenge and support when engaged in shared activity. Mediated interaction provides the disruption to existing structures required for learning to occur. Cole (1996, p.103) refers to this as 'the dual process of shaping and being shaped' and goes on to suggest that viewed in this way, learning cannot easily be broken into constituent parts, but should be viewed holistically, as a dialectic between subject, object, person and environment. Daniels (2016, p.13) presents this mediated mutual development as an assumption that 'mind emerges in the joint mediated activity of people' and that as such, thinking, learning and developing are co-constructed, distributed processes.

There are correlations here between mediated, socially constructed learning, as described above, and emergent system change attributed to a CAS. Both present a view of learning within groups whereby individual change is difficult to extrapolate from changes across the system. Vygotsky's adage that it is through others that we develop ourselves, and Bruner's (1996, p.21) interpretation of interactive learning as learners 'bootstrapping' one another relate closely to more contemporary notions of 'co-creating ourselves' (Jörg, 2009) and the co-active, co-nested, 'distinguishable, but ultimately intertwined' nature of teachers and learners (Martin and Dismuke, 2018, p.23). Erickson (1996, p.33) explains why attempting to pinpoint distinct products of individual learning might be futile

> 'Teachers and students interact in classrooms, they construct an ecology of social, cognitive relations in which influence between any and all parties is mutual, simultaneous and continuous.'

Guanglu (2012) similarly suggests that teaching and learning share a dynamic, recursive relationship characterised by mutual influence. Doll (2000) agrees, suggesting that teaching and learning could more usefully be thought of as a dialogue, rather than a linear, causal mechanism. Similar notions are presented in complexity classroom analysis wherein group learning is sometimes described as being greater than the sum of individual's contributions. Learning and development constructed using cultural and psychological tools, what Vygotsky (1978) referred to as auxiliary stimuli, will necessarily be mediated by the time and place in which the learning activity occurred, implying that no two instances of group learning will be the same. The highly situated nature of CASs is something emphasised repeatedly in the complexity education literature. The nested nature of schools (Davis and Sumara, 2006) and the openness of the nested systems (neurological, individual, group, class, school, community etc) means that what learning emerges in a given classroom small group is the result of 'uniquely configured events' Clark and Yinger (1987, p.18). A conception of learning as co-constructed, mediated and distributed emphasises the active involvement of individual agents in their own and others' learning. In a CAS, adaptations which occur within the system are in part a function of individual agents acting out of mutual self-interest and resulting changes are often qualitatively and / or quantitatively beyond the contribution of any single agent (Hatfield, 2012; Newell, 2008). Although pupils within a classroom collaborating towards a shared learning or activity goal could not be described as acting entirely out of self-interest, at group and whole class levels, given sufficient time and autonomy, convergent goals routinely become undermined by the divergent volition or resistance of individuals. This resonates with Daniels' (2016) idea of 'mind' emerging though joint mediated activity. The implication that something intangible arises when human agents collaborate, which has the potential produce novel and unpredictable outcomes is central to both socio-constructivist and complexivist lenses; viewed through the former as co-construction, and through the latter as emergence.

The focus here is on the system and the complex, pluriform nature of learning interactions rather than on individual contributions or outcomes. This sort of framing is broadly causal, in the sense that interactions within the system ecology are antecedents to learning and development. However, both socio-cultural theory and complexity thinking (CT) resist the urge to locate the 'teaching' solely with the teacher and the 'learning' solely with the pupil or suggest that one always follows the other with spatial-temporal contiguity. This contrasts with the ways in which classroom learning is typically organised and how teaching and learning are broadly understood, both within and beyond the profession, where learning is generally portrayed as a product acquired by pupils because of teacher input.

2.3 Learning in small groups

The previous section explored the social nature of learning, presenting arguments that interaction lies at its heart. However, broad depictions of a relationship between social interaction and learning leave questions about the causal detail of this relationship. According to Byrne (1998) the social is also always necessarily complex which makes problematising the teaching-learning nexus and its outcomes challenging. In school classrooms this complexity is mitigated against through a variety of organisational structures; typically referred to as enabling constraints, which according to Biesta (2009) are one way in which educational learning differs from explorative learning. This section looks closely at how the structure of small group collaboration is used to this effect, how group work is commonly choreographed in primary classrooms and the implications for learning.

Small groups impose constraints on classroom complexity in that they limit the overall density of interactions by placing boundaries around who interacts with whom. They are enabling in the sense that a lower density of possible interactions increases the likelihood of every pupil interacting, being heard, hearing others and of novel insights emerging. Working in small groups also represents economic use of time for many activities and objectives in primary classrooms. It also feels natural for a variety of reasons, as Mennin (2007) states, to work in groups 'is human'.

The literature reviewed here falls broadly into two epistemological categories. One I refer to as the 'what works' literature (Pellegrini and Vivanet, 2020; Lingenfelter, 2015; Morrison, 2012; Biesta, 2007), which tends to characterise learning as discrete, measurable, individual products and has its origins in prevailing educational research and policy paradigms, which seek concrete evidence to answer questions such as *what should teachers do to optimise (individual) learning outcomes?* For the purposes of this study, the scope of 'what works' is conceived more broadly than is typical, to include not just policy and publication resulting from evidence-based random controlled trials (RCTs) (whatworksnetwork.org.uk, 2021; Teaching and learning toolkit (EEF), 2021), but also insights from across the educational research purview which is predicated on direct causal links between teachers' work and pupil learning outcomes. This includes the vast majority of research on teaching and learning. The 'what works' policy project and the cannon of classroom-based educational research do differ from one another. The former is characterised by RCTs and policy prescriptions whilst the latter includes greater diversity of approach and less rigid interpretations of teaching and learning, however I consider both to be functions of a shared mindset which presumes learning to be (broadly) caused by teaching. The other category I refer to as the complex systems literature which, for reasons introduced in Chapter One, resists the urge to view learning as a series of unitary products acquired by individuals as a direct, causal consequence of teaching, and instead seeks to *understand ways that educational systems (including schools, classrooms, groups, individuals) change through the networked interconnectivity of their agents*. To clearly differentiate these two agendas in the literature, that which I categorise as 'what works' tends to embrace the central characteristic that education is in and of itself purpose-driven, whereas the complex systems literature tends towards ambivalence to this characteristic. In the following sections, the two bodies of literature (if they can be considered in this way) are drawn upon, beginning with 'what works' and then introducing perspectives from complexity. Obvious tensions between the two paradigms are explored later in this chapter. Most of the data for this study was collected from small group classroom activity, therefore understanding small group learning is important.

Typical organisation of pupils in primary classrooms involves small groups within the whole class group, what Davis and Sumara (2006) refer to as decentralised structures (see section 6.1.1 in Chapter Six). Small groups take various forms, typically including dyads and triads up to table groups of five or six pupils. Sometimes group activities involve collaboration in which pupils work on shared tasks with shared materials, processes and goals. Sometimes the goals and processes are the same or similar but individually pursued, in which case the notion of a 'group' is more locational (sitting around the same table) than collaborative. Groups can be deliberately formed of pupils of perceived similar capabilities and sometimes they are intentionally 'mixed ability'. Either way, the assumption is that the concomitant interactions arising from the group members' proximity, connectivity and collaboration will elicit learning for the individual members and produce shared understandings that may not have been reached by everyone individually. Different group compositions (including degrees of teacher involvement) and different collaborative activities will necessarily generate interactions that are qualitatively and structurally varied.

Verbal interaction is at the heart of group learning. Considerable attention has been given to relationships between interaction and learning in group work, and the variety of factors which influence the quality and usefulness of pupil talk. There is a consensus in the literature on interactive group learning that merely placing pupils together around tables does not automatically invoke learning (Alexander, 2017; 2018; Resnik, Asterhan and Clarke, 2015; Mercer and Hodgkinson, 2008; Mercer *et al.,* 2004; Corden, 2001; Mercer, 2000). Leung and Lewkowicz (2013) found that the effectiveness of group learning depends more on pupil agency and role-taking than on mere participation. Galton and Hargreaves (2009) noted that trusting relationships between pupils were essential for group talk to be effective in promoting learning. Solutions to the pedagogical challenge of configuring group interactions in the interest of curricular learning vary, but all seem to involve imposing structure on pupil (and teacher) interactions.

There exists a considerable pool of research suggesting a positive correlation between collaborative small-group work and pupil learning (see Alexander, 2018; Mercer and Littleton, 2007; Slavin, Hurley and Chamberlain, 2003; O'Donnell and King, 1999; Webb and Palincsar, 1996; Galton, Simon and Croll, 1980). Notable throughout the literature, however, is the idea that not all group work is considered equally valuable or worthwhile. Galton, Simon and Croll (1980) showed that whilst primary pupils often *sat* in groups, they rarely *worked* in groups. Task-focussed exchanges between pupils were found to be dominated by exchanging information rather than discussing ideas (Galton *et al.,* 1999). Two noteworthy explanations for this appear in multiple studies, both relating to pedagogical approaches prevalent in UK primary schools. Firstly, the composition of pupil groups is often organised with ease of classroom management in mind, with the consequence that pupils are placed in proximity to those with whom they are least likely (rather than most likely) to talk. Secondly, that typical interactive orientations of primary classrooms emphasise teacher-pupil, rather than peer-peer interactions (Baines, Blatchford and Kutnick, 2008; Baines, Blatchford and Chowne, 2007; Kutnick, Blatchford and Baines, 2002; Blatchford *et al.*, 1999). Teachers typically plan for their interactions with pupils but less often for interactions between pupils. This is perhaps not surprising since, compared to didactic instruction, collaborative group activity increases unpredictability, presenting greater managerial challenges for teachers. A study by Cohen and Intilli (1981) revealed that teachers' concerns about group work included loss of control, increased disruption and off-task behaviours. Concerns raised in other studies include beliefs that pupils are not capable of learning from one another (Cowie, 1995) and that learning arising from interactive group work is difficult to assess (Plummer and Dudley, 1993).

In order to understand why enabling constraints seem to be a pre-requisite for productive activity in interactive group work, it is useful to consider the consequences of not applying them. If tangible learning is a consequence of group functionality, then there are several factors, mostly related to group social dynamics, which might lead to dysfunctionality. London and Sessa (2007, p.355) state that it is a tall order in any group to coordinate 'members, tasks and tools in ways which allow the group to complete its work, fulfil member needs, and maintain the group well-being'. Dysfunctionality, they posit, is characterised by both chaos and conflict, which correlates with one of the key concerns teachers had in Cohen and Intilli's (1981) study. Galton and Hargreaves (2009, p.4) also highlight positive relational dynamics as a pre-requisite to functional interactive group learning. They state that to reach desired learning outcomes pupils must 'learn how to trust and respect each other.' Examples of dysfunctionality arising from poor relational dynamics include one or more group members dominating discussion and resources, conflict over roles, resources and airtime, off-task behaviours, poor management of distractions, lack of turn-taking and resistance to collaboration. Suggestions that pupils should be actively coached in effective talk for learning strategies (Webb and Mastergeorge, 2003; Gillies, 2003) also extend to social and relational skills. There are now numerous schemes of work available to primary schools which support pupils' social-emotional development. Baines, Blatchford and Chowne (2007) highlight the importance of a relational approach to interactive group work, stating that compromise and the avoidance of 'petty disputes' is paramount (p.666). They go on to explain that a central aim of group work is independence, and that for this to develop pupils ought to be able to collaborate harmoniously with others regardless of personality types, resolving problems together. Jolliffe (2012) points out that children do not come to school equipped with the social skills required for effective collaborative group work. In her view, skills such as communication, leadership, trust-building and conflict management should be actively taught by teachers and pupils should be motivated by teachers to apply such skills.

The apparently unhelpful presence of social conflict as described above is a feature of all classrooms, but should not be confused with cognitive conflict, which according to Piaget is a necessary pre-requisite to cognitive development. Though learning in groups was not central to his research, Piaget noted the value of critical exchange and that equitable peer to peer interactions are a productive site for disagreement and resolution of differences, which can be a potent source of progress in cognitive development. 'Criticism is born of discussion and discussion is only possible amongst equals.' (1932, p.409). I would argue that this depends to an extent on one's definition of 'equal'. The pupils in this study were equal in several ways (age and cohort for example) but unequal in others (social status, personality traits etc) and these points of sameness and difference were influential on learning. Mercer and Littleton (2007, p.10-11) posit that

> '[…] disagreements with other children serve to highlight alternatives to the child's own point of view. Since the alternatives can be considered on equal terms and the resulting conflicts of opinion necessitate resolution, the children involved can be

> prompted towards higher level solutions, which reflect the partial insights reflected in their initial positions.'

They go on

> '[…] the germs of intellectual progress are seen in the conflict of perspectives.'

The collision of ideas is central to depictions of the classrooms as a CAS. Davis and Sumara (2006) discuss the importance of establishing a culture and climate with sufficient openness for pupils' opinions to emerge and bump into one another. They argue that learning depends on pupils influencing one another's thinking and that the classroom system should facilitate this. The implications here are firstly, that disagreement is a catalyst for learning and secondly, that what emerges from group cognitive conflict is greater (more accurate, more refined, more novel, clearer) than the sum of the individual contributions. These propositions have been researched repeatedly (Perret-Claremont, 1993; Doise and Mugny, 1984; Mugny, Perret-Clermont and Doise, 1981; Perret-Claremont, 1980) building a consensus that cognitive conflict, and the socially engendered necessity to resolve it, gives rise to evaluation and re-evaluation of ideas, leading to higher order thinking and solutions. However, as stated in Chapter One, studies have tended to observe groups under inauthentic conditions where on-task behaviours are likely to have been more prevalent than in authentic classroom settings. Social and cognitive conflict typically coexist in primary classrooms, the former typically being seen as obstructing the latter, leading teachers to apply measures to suppress the likelihood of social conflict in the interest of cognitive conflict. This is not surprising since inevitable social challenges in the everyday functioning of primary classrooms, and underling pupil social subcultures, can form obstacles to concentration and productivity. This relationship between social and cognitive competence was illustrated in a study of classroom activity by Rosenshine (2015) which revealed that pupils spent approximately 40% of each day actively engaged in academic activity, with the remaining 60% divided between interim activities (sharpening pencils, giving/receiving books, handing work in etc) or off-task activities (socialising, daydreaming, misbehaving). Time not engaged with substantive academic activity or interactions was also negatively correlated with the quality of engagement during the 40% of 'on task' time. A study of classroom mood by Canovi *et al.*, (2019) showed that pupil emotions and agency, including interpersonal regulation and resistance, influenced the cognitive landscape of the classroom.

Links between quality of pupil interactions and learning are well established in the literature and according to Staarman, Krol and van der Meijden (2005) can be analysed through social-behavioural or cognitive-developmental lenses. Social-behavioural approaches look at learning through peer interaction when group members work towards a shared goal. Motivation and social cohesion driven by collaborative aims encourage group members to learn from and with one another. As previously discussed however, social cohesion cannot be taken for granted in classrooms. The cognitive-developmental frame emphasises the socio-cognitive and socio-cultural aspects of pupil interactions leading to shared constructions of knowledge. A consistent explanation for the value of interactive group work, pertinent to cognitive developmental analysis, is that peer interaction can provide rich opportunities for pupils to reflect on the utterances, perspectives and reactions of others. This correlates with both Piaget (1932) and Erickson's (1996) views and was referred to by Webb (1991) as the cognitive elaboration approach, describing the cognitive processes learners use such as explanations, representations and argumentation, and the elaborated speech which can arise from them. Studies (Webb *et al*., 2014; Howe, 2010) have shown that elaborated forms of speech can have positive modifying effects on cognitive structures when peers work together, though Mercer and Littleton (2007) point out that instances of productive peer to peer elaborated dialogue are rare. According to Barnes and Todd (1977) small groups are rarely inherently productive without specific framing of tasks and teacher intervention. Among the variables which explain these findings are group composition, how groups are formed, pupils' social skills, task type and teacher understanding. Slavin (2014) identified differences in effects between pupil groups depending on whether groups were naturalistic (friendship) or deliberately formed (strategic). Baines, Blatchford and Chowne (2007) explain how pupils' collaborative and social skills determine how successfully they perform on group tasks. Teacher understanding and acceptance of the principles of group work are also contributing factors in the variability of learning arising from group tasks according to Slavin *et al.*, (2013). Tasks and their contexts, according to Sampson and Clark (2009), also influence the learning outcomes of group work because they determine what pupils are collaborating on, expectations about how they interact with one another and the rules, or patterns of behaviour particular to a given classroom context. Running through all these accounts is the suggestion that without strategic configuration, rehearsal of group working skills or conditions which promote on-task (more than off-task) behaviours there is no guarantee that group work will result in learning.

Complexity-framed research into small group activity is limited, perhaps due to the generally held view that complex behaviours only emerge in systems of great scale, consisting of large numbers of agents. Cilliers (1998), Williams (2011), Holland (1992; 2006), Carmichael & Hadzikadic (2019), Golstone & Sakamoto (2002) and Waldrop (1992) all see system scale as a prerequisite for complexity (see Knight, in press for a discussion of this). However, complex behaviours have been noted in small groups (Mennin, 2007; Arrow, Mcgrath and Berdahl, 2000), based on the observation that in complexity terms 'scale' refers more to the density and quality of interactions within a system, than its number of agents. Small groups can certainly produce large numbers of interactions derived from a networked array of personal and interpersonal differences through which pupils affect one another. Hardman

(2015) suggests that group dynamics are influenced by composition because individuals bring their own pluralities to the shared experience. Internal diversity is a key concept in CAS framings of group learning (Mennin, 2007; Davis and Sumara, 2006; Davis, 2004) referring to the many counterpoints and asymmetries which individual learners bring to collective activity and which prompt critical incidents to emerge. Diversity in this sense is not limited to contemporary interpretations of demographic or identity markers, but includes a range of subtler differences including knowledge, skills, personality traits, personal histories, mood, values, beliefs, confidences and competences including down to the neurological level. Arrow, Mcgrath and Berdahl (2000) suggest that homogeneity in groups can limit the variety of perspectives shared, which also limits creativity. According to Mennin (2007) it is the exchange of differences among small group members which produces self-organised behaviours and gives rise to new learning. In CASs, diversity is complemented by the concept of redundancy, which Davis and Sumara (2006) explain as duplications or excesses of useful overlaps between group members. If every pupil is different in every way such diversity would make productive interaction difficult, but having similar perspectives, knowledge, skills and temperaments represented within a small group introduces stability and scope for agreement and confirmation.

The learning potential of small groups is discussed in the literature in terms of what forms of learning can emerge, mechanisms by which this happens and the characteristics of small groups which make them conducive to learning. There is consensus that (contingent on groups and activities being appropriately configured and social skills being sufficiently developed) working in groups has the potential to develop children's thinking skills (Littleton and Mercer, 2013; Mercer and Littleton, 2007; Mercer, 2000) argumentation (Sandoval, 2019), conceptual change (Dawes *et al.*, 2010; Harlen, 2005), vocabulary (Cabell *et al.*, 2015; Silverman and Hartranft, 2015) and motivation (Chiriac, 2014). Descriptions of how these forms of learning develop through group interactions, however, are dominated by analysis of pupil dialogue transcripts in relation to learning intentions and have not evolved significantly for several decades. Explanations of learning through interaction still draw heavily on the concepts of scaffolding (Wood, Bruner and Ross, 1976) and interpretations of Vygotsky's Zone of Proximal Development (ZPD) (1978) in which the tutoring support of a teacher stretches a learner beyond what they can currently achieve unaided. Other than somewhat low-resolution depictions of one pupil's ideas challenging the existing ideas of another, or pupils simply being more willing to articulate their thinking in a small group context, insights into how learning emerges from group interaction remain somewhat elusive in the literature. A reason for this is no doubt because many of the processes involved are complex and tacit. Given that individuals in any group learning context have their own levels of interest, motivation and self-regulation, their own unique histories, their own experiences external to the classroom, their own intellectual and non-intellectual pre-requisites and developmental trajectories; and given alongside this that pedagogic practices vary from one classroom to another, it is not surprising that locating more precise explanations for how and what learning emerges in group collaboration has proved challenging.

A significant factor which emerges repeatedly through the 'what works' literature is that of teacher-imposed structures intended to give shape to small group work in the interest of pupil learning. Enabling constraints take a variety of forms and can include task structure, time limits, group composition, group member roles or the teaching of specific dialogic structures. Viewed through the lens of complexity thinking, these enabling constraints are described by Davis and Sumara (2006, p.145) in the following way

> '[…] the structural conditions that help to determine the balance between sources of coherence that allow a collective to maintain a focus of purpose/identity and sources

of disruption and randomness that compel the collective to constantly adjust and adapt.'

Change emerges when complex systems teeter on the edge of chaos, not when they fall into it, therefore the balance between coherence and disruption is crucial in producing sufficient randomness to allow for the emergence of unpredictable possibilities, whilst being sufficiently constrained to maintain a degree of organised unity. In CASs found in nature or in human organisation at very large scales such as cities, enabling constraints form organically as the system evolves. In the context of primary school classrooms however, enabling constraints such as collaborative group work are created by design and imposed by centralised control emanating from the teacher. Such constraints governing interactive group work include structured activities, set durations, physical organisation of the classroom and of workspaces, group composition, individual pupil roles, success criteria and mechanisms to ensure inclusivity. Biesta (2016, p.204) describes the effect of such constraints as 'reducing the openness of the system' and goes on to state that to an extent, the functionality of a nested school system (small group, classroom, key-stage, school) depends on such complexity reduction. This endorsement also comes with a warning however, that there are tipping points beyond which 'complexity reduction turns into unjustifiable control'. There exists a consensus within the literature that small group work should be 'managed' and not left to chance, which implies there is merit in teachers carefully planning certain aspects. One might legitimately ask where the line exists between constraints which enable and constraints which limit unnecessarily? One of Biesta's (2016) 'tipping points' in this balance concerns the moment where pupils can no longer exercise initiative and take on responsibility, but instead become 'objects of intervention' (p.205). For a teacher, the benefits of crossing such a tipping point may be easier classroom management or attainment of a short-term learning objective for pupils, but the cost might be the development of pupil independence, maturity, and self-regulation.

This balance between coherence and randomness in classroom activity runs throughout the research literature on classrooms as CASs (Hardman, 2010, 2015; Sullivan, 2009; Newell, 2008; Davis and Sumara, 2006) and is at the essence of arguments about the usefulness of CT as a framework for analysing classroom learning. In his study of two classrooms Newell (2008, p.13) found that classroom activities which were 'sufficiently focussed to encourage coherence among student responses and simultaneously sufficiently open-ended to allow serendipitous randomness into the conversations' were a productive site for emergent learning. In his study of three high school classrooms Sullivan (2009) found the degree of structural constraint imposed by teachers to be the most significant determinant of whether emergent learning was evident, using the term 'keystone species' (p.185) to describe the structural influence teachers have over classroom proceedings. Davis and Sumara (2006) emphasise the influence that teachers exert in locating balance between overly constrictive and overly loose controls on learning. Hardman (2015) notes that controls are necessary. They keep pupils safe and help manage learning productively. Pedagogical enabling constraints are intended to encourage dialogic, discursive, collaborative and co-operative behaviours between pupils and between pupils and teachers, without suppressing the possibility of randomness and novelty, which Hardman (2015, p.54) implies would also be 'damaging'.

To summarise this section on interactive small-group work and learning, the literature presents a convincing proposition that collaborative group work can be a productive site for learning and intellectual development. Organising pupils into small groups has two main functions. Firstly, it serves a complexity reducing purpose in that there are fewer interactive variables than in whole class working. This has the effect of enhancing manageability for the teacher, though as previously discussed, group work tends to be less supervised because the teacher can only be in one place at a time, which presents its own challenges. Constraints intended to enable learning are also routinely applied to small-group work which have the effect of reducing randomness and focussing attention productively. Secondly, interactive small group work is intended to create the conditions in which pupils are most willing and able to interact with one another. The literature indicates that a range of factors, including some within the teacher's direct control (pedagogical) including group composition, task framing and roles, and some outside of it (random chance) such as personality and individual personal histories, exert an influence on what, how and to what extent useful learning is likely to emerge. Pedagogical factors assert constraints on the chance factors. A meta-theme, which hovers tangibly over all the literature concerned with learning through interactive small-group work, is the interplay between autonomy and constraint. This dynamic is of particular interest to the complexivist classroom researcher because in a CAS, change emerges when a system is on the 'edge of chaos', with sufficient order to maintain coherence and sufficient randomness to allow for the unexpected. However, conclusions from all the cited studies and discussion papers on small-group learning agree that where productive learning (of predetermined objectives) arises from group work, it is at least in part a function of teacher-imposed order. This theme is revisited in the discussion of data, in Chapter Seven.

Suggestions of different strategies for regulating pupil interaction in small-group activity raise important questions about the relationship learning has to freedom and constraint. Evidence from cited studies indicates that teacher-imposed structures correlate positively with improved learning outcomes for pupils. However, this may only be the case in the current educational paradigm in which, according to some, learning has been commodified (Ball, 2018, 2012; Shukry, 2017; Karpov, 2014) into neat packages which pupils accumulate during discrete episodes. The policy drivers of this paradigm, the resulting 'what works' epistemology (Biesta, 2007) and their combined consequences for how teaching is positioned will be discussed in the final section of this chapter. It is noteworthy that despite the considerable volume of research and discussion on small group work as a context for learning, and notwithstanding significant developments in research methodologies, explanations for why and how learning emerges in groups have not become more detailed or specific over several decades. It is possible that the prevailing 'what works' paradigm discourages researchers from examining learning processes at higher resolutions; the 'what' being currently of more interest than the 'how' or' why' to those wishing to develop evidence-based policy and practice.

2.4 CAS as a framework for understanding small group classroom learning

Complexivist educational researchers have explored ways in which characteristics of school classrooms overlap with descriptions of CASs, pointing out strengths and weaknesses in the comparison. A noteworthy point here (one reinforced by Sullivan, 2009) is that almost all the literature concerning complexity and classrooms originates from a small handful of authors, who all cite one another, the most prominent of which, Davis and Sumara's 2006 book 'Complexity and Education: Inquiries into Learning, Teaching and Research' pioneered the direction which most others have followed. Niches within educational research are nothing unusual, however this one is particularly small, and self-referential.

Burns and Knox (2011) compared De Bot, Verspoor and Lowie's (2005) descriptions of the development of complex systems over time, with their own analysis of classrooms. They found a number of correlations, including that both consist of sets of interacting variables (pupils, teachers, resources, environment), both had unpredictable outcomes (learning outcomes, critical incidents), both are part of and connected to other systems (family, institutional, community), both are sensitive to initial conditions, meaning that small changes or incidents can result in large differences over time. These qualities produce the conditions which predispose classroom systems to emergent change over time according to (Burns and Knox, 2011). Davis and Sumara (2006) posit that to really understand the dynamics of the classroom it is necessary to stop thinking linearly, a point which is supported and explained, with reference to how the social world behaves, by Byrne (1998) who asserts that outcomes are determined by multiple causes moving in non-linear ways. Typical classroom examples of this are the multiple factors which might determine whether a pupil contributes verbally or not in a small group collaboration. These might include (though are not limited to) peer pressure, personal ambition, knowledge of an answer, fear of failure, confidence level, social status, degree of interest or desire to go to lunch. Alone, in a linear assessment these factors merely demand a multivariate analysis. A complex system analysis, however, would examine the extent to which these factors to interact with one another non-linearly, something most teachers would not find it difficult to relate to.

Arguing that classrooms display CAS behaviours, Guanglu (2012) points to the non-linear, recursive nature of teaching and learning, in which pupils' and teachers' interconnections produce continuous recursions of understanding, interpretation, re-understanding and reinterpretation. Teaching and learning do not always follow this pattern, in fact, linear transmission of information remains common in many classrooms and arguments for more direct instruction are strengthening (see Ashman, 2020; Sherrington, 2019; Rosenshine, 2012), but where openness allows for sufficient randomness, learning can take on forms more akin to 'mutual fertilisation, pollination [and] active catalytic[s]' (Doll, 2008, p.14). Guanglu (2012) suggests that this mutuality is seen in the experience, commonly reported by teachers, of gaining a new or better understanding of the subject matter they are teaching, through the act of teaching it. Support for conceptualising school classrooms as CAS also comes from

Hardman (2015) who asserts that the sudden or unanticipated emergence (bifurcation) of novel outputs in classroom activity are inevitable, partly due to the internal diversity of classrooms, including the uniqueness of individual pupils' (and teachers') brains. Classroom systems are nested among, sit within and interact with other systems, including small groups and individuals. Taking the position that actions, interaction, responses and speech are embodied representations of neural activity, he draws on Cillier's (1998) model of the brain as a distributed network to illustrate the important role that personal histories and experience play in how individuals respond to interactive learning situations, Hardman (2015) explains that 'the current state of a neural network when it receives new stimuli will influence how the network adapts' (p.123). This means that an individual's accumulated experiences to date shape how he or she learns. Neural diversity, therefore, is one factor contributing to the diversity of perspectives, ideas and utterances which individual pupils bring to bear on collaborative activity, and which throw up random critical incidents, or bifurcations. One of the aims of this study was elicit examples of how internal diversity produces such bifurcations. Sullivan (2009) agrees that classrooms can be considered complex, being well-networked, behaving in non-linear ways and showing emergence. Though his tentative language is instructive about the confidence with which he makes this assessment. Clearly there are reasons to doubt the efficacy of the comparison.

A few suggestions are evident in these descriptions which lend support to the framing of classroom small groups as CASs. Firstly, that classrooms have moving parts which, given sufficient opportunity to interact, will produce bifurcations at different nested levels. Secondly, that perturbations arising from such bifurcations are causally connected to learning insomuch as randomness changes interactive behaviours and injects novelty which can qualitatively change learning states. Thirdly, there is an implication that even where learning is characterised by linear transmission and teacher control, openness is inevitable to some degree. Despite the structure of organised schooling, the structure of curriculum and the necessary order imposed by teachers, diversity arising from the openness of classroom systems creates opportunities for randomness, unpredictability and non-linear change. These characteristics also invite bottom-up emergence, even where and when it is not intended. Accounts of learning arising from distributed, self-organised, environmentally sensitive neurological processes, which both introduce and respond to diversity within classrooms correlate with depictions of classrooms as CAS. Emergence, via moments of bifurcation which present possibilities for novel understandings are consistent with arguments that classroom learning is ‘complex, historically contingent, non-linear and sensitive to context’ (Hardman, 2015, p.148).

An example of non-linear emergent learning is evident in the common understanding that alongside the top-down influence of the teacher, pupils also influence and change one another through mutual self-influence (Davis and Simmt, 2003). The flow of content, explanation and questioning does not only travel unidirectionally from teacher to pupils and result in the development of neat predictable knowledge, understanding and skills. Alexander, Shallert and Reynolds (2009, p.178) point out that ‘change that happens in the learner, be it dramatic or imperceptible, or immediate, or gradual, exerts a reciprocal effect on the learner’s surroundings’. This depiction adds weight to comparisons between small group activity and CASs because small groups are intended to facilitate a flow of information and influence between pupils, towards the classroom environment and climate and, presumably, back towards the teacher as well. This suggests that as group members change, they also change one another, the teacher and their surroundings, including the environment, through their mutual interconnectedness, much like the behaviour of a CAS. Davis and Sumara (2006) refer to this phenomenon when stating that complex systems are systems which learn. Within such systems, they suggest

> 'One cannot reliably predict how a student or a classroom collective will act based on responses in an earlier lesson, or sometimes a few minutes previous. In other words, strict predictability and reliability of results are unreasonable criteria when dealing with systems that learn (2006, p.18)'

This means that even in small group activity, change (learning) is unlikely to only unfold entirely as intended or directed by the structures of organised schooling, the curriculum, or the teacher. The system and its constituent agents will also adapt and change in ways not predicted or intended by those governing structures. Haggis (2008, p.165) suggests that emergence is always at least partly unpredictable, stating that 'what emerges will depend on what interacts, which is at least partly determined by chance encounters and changes in environments.'

A principal 'learning' characteristic of classrooms according to complexivists (Hardman, 2010; 2015; Burns and Knox, 2011; Sullivan, 2009; Newell, 2008; Davis and Sumara, 2006) is their tendency towards self-organisation and self-maintenance, what Sullivan (2009, p.26) refers to as 'adapt[ing] of their own accord.' Some degree of self-organisation is inevitable in any system which is not entirely mechanistic and deterministic and since wholly determining the opinions, predilections, desires, impulses, thoughts and behaviours of groups of pupils is impossible (not to mention undesirable), self-organisation seems inevitable, even within the constraints of small group organisation. It seems worthwhile to ask however, to what extent this phenomenon can be said to positively influence learning. In a CAS such as an ant colony, immune system or decentralised finance block-chain, the self-organisation and its concomitant adaptation *is* the learning. The fluctuation and interaction of many agents (be they ants or genes) all influencing one another, all influencing the system and being influenced by it, produces change which exceeds the individual possibilities of the agents. However, this analogy does not translate perfectly into school classroom or small group systems because, as Biesta (2009) points out, education is not a morally neutral activity, but a purposeful, values-orientated one and because of this, what is learned matters. He argues that describing learning as whatever emerges because of classroom interactions ignores the fact that education exists so that people learn something, not just anything. Menter (2016) similarly asserts that teaching has an inescapable moral dimension to it. Classroom learning is purposeful and values orientated. These arguments correspond with others (Kuhn, 2008; Egan, 1997) that a CAS framework has considerable limitations when analysing classroom learning, because classroom learning is goal-orientated and has prescribed directions in which teachers must steer all pupils. As Kuhn (2008, p.178-179) puts it

> ‘It may be argued that there is a fundamental mismatch between complexity and educational enterprise as in essence complexity is descriptive whereas education is normative, or goal-orientated. {…} complexity offers organisational principles for describing how the world and humans function. Education, however, is orientated towards achieving certain goals’.

These descriptions of the purposes of education are demonstrably incompatible with depictions of CAS, in which higher complexities may emerge due to agents operating individually out of mutual self-interest. As Kuhn (2008, p.179) goes on to state ‘complexity merely describes, whereas education aims to make a difference.’ A consequence of this purposefulness which characterises education (and which distinguishes it from learning in the general sense) is the centralised control of the teacher.

As previously discussed, teachers impose expectations and structures on classroom activity, and do so in the interest of curricular aims and purposes. Biesta (2009) refers to this as teachers introducing ‘an asymmetrical element into the educational process’ which is ‘one of the main reasons why educational learning is radically different from collective, interactive, explorative learning' (p.31). Without the imposition of purposive structures, the likelihood of learning aligning with curriculum aims may be too low and the risk that nothing of curricular value will be learned, potentially too high. Ramussen (2005, p.219) agrees that educational learning has 'special intentions in mind', describing teaching as a 'social arrangement and organisation aimed at intensifying possibilities for learning and the results of learning'. The absence of any overarching 'special intentions' in a CAS found in nature weakens the case for classrooms being viewed as CASs. Sullivan's (2009) study illustrates this. Not all the classrooms studied by Sullivan were considered to be complex. He suggests that a key factor in whether a classroom can usefully be classified as a CAS is whether adaptations within the system are triggered by the teacher or by the collective. If the teacher orchestrates all or most responses to daily events with little involvement from the pupils, then adaptations cannot be described as bottom-up.

In concluding he states

> 'One may say that classrooms are inevitably complicated, and I would certainly agree. One may even say that all classrooms exhibit some measure of complexity, and I might agree. To assume, however, that a class will network itself in such a way that it adapts in any meaningful way is too much to assume.' (p.170)

A presumption in the present study was that in decentralised group work contexts there exist plenty of opportunities for pupils to orchestrate adaptations and that novelties which arise within group work are likely to have bottom-up, emergent properties. Radford (2008) bridges arguments for and against comparisons between classrooms and CASs using a metaphoric continuum between what he refers to as 'clockishness' and 'cloudishness'. He draws on Popper's (1979) assertion that all systems can be viewed on a continuum between deterministic, reducible and predictable (clockish) on one hand, and indeterminate, unpredictable and open (cloudish) on the other. Radford's contention is that even the most deterministic systems, such as clocks, have degrees of unpredictability, and that likewise, the most open systems, such as clouds, have some degree of predictability. Viewed at sufficient resolution, a clock will reveal its lack of mechanistic causality and a cloud will reveal its causalities. All phenomena, according to Radford, can be thought of as having degrees of both 'clockishness' and 'cloudishness'. The question is which is the most useful or accurate explanatory framework for depicting classroom small groups. Some researchers have attempted to describe the 'cloudish' features of classrooms and how exploring them might lead to new insights about classrooms and classroom teaching and learning.

Semetsky (2005) for example presents a radical vision of a self-organised classroom, characterised by distributed control, pupil autonomy and an absence of direct instruction. She posits that this would 'naturalise the concept of learning' (p.31) through the introduction of greater choice for pupils. She envisages a classroom in which there are no right or wrong responses or answers, just an array of choices for pupils, creating an environment with an 'inherent incapacity for students to experience failure at any point within the process' because there is no 'special educative aim' (p.31). This considerably more cloud-like than clock-like vision of classroom learning would require a radical overhaul of curriculum structures, possibly of the very purposes of education. Semetsky acknowledges that this radical vision has the potential to be counter-productive, however. She draws on Cillier's (1998) warning about chaotic system behaviours or 'catatonic shutdown' (p.119) and suggests that a multiplicity of pupil options may contribute to complete disorganisation rather than self-organisation. Waldrup (1992) also notes limitations with extremes of system behaviour, asserting that whilst frozen (clockish) systems can benefit from 'loosening up a bit', turbulent (cloudish) systems 'can always do better by getting themselves a little more organised' (p.295). Morrison presents a similar critique, and asks

> ‘whether self-organization is such a good thing, or whether it will lead to diversity, inefficiency, time wasting, mob rule, and a risk of people going off in so many different directions that the necessary connectivity between parts of an organization, its values and direction will be lost or suffocated’ (2006, p.7).

This is a valid question. Judging when sources of novelty and disruption risk undermining sources of coherence within a system is crucial to maintaining productive edge of chaos states and is a crucial aspect of teacher professional judgement. In a CAS such equilibrium is maintained through agent self-organisation. In a classroom it is largely due to the influence of the teacher; perhaps an illustration of why the concept of classroom as CAS both is, and is not, accurate and useful.

Others present visions of classrooms as self-organising adaptive systems which are less adversarial to the purposes of education than Semetsky’s. Fong (2006) for example, suggests that the concept of self-emergent order is well suited to early learning environments because of their natural tendency to balance the ‘dual worlds of emergent order and imposed control’ (p.1) and the challenges teachers face in managing the latter in busy classrooms. Sullivan (2009) is also open-minded about the classroom as a CAS, positing that in classrooms where self-organisation, distributed control and agent-interaction (the more cloudish characteristics) are maximised, novel learning emerges. Defining emergent learning as the ‘acquisition of new knowledge by an entire group when no individual member possessed it before’ (p.i) Sullivan suggests that some curriculum subjects lend themselves more than others to the conditions in which such learning might emerge (literacy more so than mathematics in his example). One such feature of CAS which might be emphasised and capitalised upon in the interest of small group learning is neighbour interactions. In their study of Canadian mathematics teachers Davis and Simmt (2003) noted that with sufficient density of short-range pupil interactions and networking, the emergence of novelty was likely. Their concept of neighbour interactions includes, but also stretches beyond, pupils sitting on the same table. They emphasise that ‘neighbours in a knowledge-producing community are not physical bodies or social groupings. Rather, the neighbours that must ‘bump’ against one another are ideas’ (p. 312). They recommend maximising conditions in which pupils’ ideas can collide, not just between neighbours on tables, but across the nested topography of the classroom system, because ‘agents within a complex system must be able to affect one another’s activities’ (Davis and Sumara, 2006, p.142).

2.4.1 Summary of group and class learning and the efficacy of CAS analysis

To summarise this overview, learning is both the transformation of individuals, through individual and shared endeavour within a system, and, according to complexity thinking, the transformation of the system itself through self-organisation. Learning at these two levels also influence one another, since changes in the behaviour of the collective (system learning) impact on changes in its members (individual learning). At both levels however, change is a consequence of some form of disruption to existing structures. Curriculum necessity and standardised assessment (among other factors) in education, however, imbue teaching and learning with purpose which necessarily privileges a focus on individual learning over that of the system, and necessitates the imposition of top-down structures from teachers. Thus, the interplay of bottom-up emergence and top-down control via enabling constraints, create a learning environment which is neither wholly clockish nor wholly cloudish, but degrees of both.

Learning in small groups is sensitive to initial conditions, such as group membership, task orientation, physical environment and the co-ordination between top-down and bottom-up organising principles. Small groups are ambiguously bounded because pupil connectivity crosses nested levels of group, classroom and institution, as well as beyond the institution. This can be considered a strength of the classroom system and an argument for using a complexity lens to analyse group activity and outcomes, though generalising about small group or whole class learning is difficult due to the considerable variability in classroom cultures, organisation, and management from one school to another.

Legitimate arguments can be made for and against the usefulness of conceiving the classroom as a CAS, suggesting that this framing presents both opportunities but limitations. It is undeniable however, that even small groups with their reduced complexity do not behave in fully mechanistic, linear, or causal ways and that some degree of systems thinking is likely to be helpful for understanding their less predictable aspects. Based on the preceding discussion of convergence and divergence between classrooms and CAS, it might be reasonable within the current educational climate to describe primary classroom small group activity as broadly clockish with cloudish tendencies.

2.5 Education policy and the simplicity phenomenon

Set out in the introduction to this thesis, and one of the motivations underpinning the research, was the objective of representing primary classroom learning in a more authentic light than is commonly portrayed. This means representing its complexity. As previously stated, virtually all media depictions of school teaching and learning imply a mechanistic, causal, input-output model in which to improve the outcomes it is only necessary to improve the inputs. Politics also inadvertently frames teaching and learning this way, predicated as it is on a utilitarian epistemology (Smith and Larimer, 2009) which privileges policies which purport to bring the most overall benefits. This approach both helps create, and feeds on, the ‘what works’ approach in education (discussed further in Chapter Three). According to this epistemology, policy tweaks and pupil learning outcomes are directly causally linked.

The tendency towards reductionism in media representations of education have been noted by several authors. Mills and Keddie (2010) note that the media is a powerful cultural force which tends to create the realities it describes. Snyder (2008) posits that the media has the reach to shape national constructions of schools and teachers. Baker (2000) acknowledges that ‘sound-bite’ culture leads to over-simplification of education ‘stories’ in news media, describing journalists as ‘simplifacteurs’ who must chart a course between satisfying the lay public and assuaging education experts. Though, as Levin (2004) points out, the paying audience comes first, which necessitates reduction of complex issues into digestible morsels. Levin goes on to illustrate how this proclivity is deeply rooted in both media and politics, stating that ‘being able to put issues simply’ is a requirement in both fields because ‘anything beginning with “This is a complex issue” is likely to result in most people ceasing to pay attention’ (p.278).

This inclination to present education issues as simple and fixable creates an influential and seductive, if limited, portrait of teaching and learning; and representations which are readily consumed by a society with a desire for simplicity. The challenge to authentic representations of education is that simple descriptions of complex human social phenomenon are always inaccurate to a significant degree, as Mencken (cited in Ciotti, 1983) put it ‘For every complex problem, there is a solution that is simple, obvious, and wrong’ (p.37). Nevertheless, simplicity has an alluring appeal. Taylor (2001, p.137) suggests that the attraction of simplicity goes back a long way in human cultures, calling the reduction of complexity to simplicity ‘one of mankind’s most ancient dreams’. This is, of course, understandable.

Human societies tend to organise themselves in the interest of efficiency. The world is inordinately complex and to function in it, humans rely heavily on their ability and natural propensity to reduce it into manageable forms. This habit also has evolutionary, neurological and conceptual bases, evidenced in the way that humans streamline perceptual information into manageable conceptual categories. Gelman and Kaylish (2006, p.688) explain concept development as 'an efficient means of representing and storing experience (obviating the need to track each and every individual interaction or encounter)'. This accounts for the human ability to use acquired knowledge across a variety of situations, which require some form of abstraction or generalization (Sloutski, 2010). For all intents and purposes the urge for simplicity is hardwired in human beings.

In education discourse the principal simplification concerns cause and effect. Whilst rarely articulated explicitly, the suggestion that the only significant causal variable influencing pupil learning is teacher input permeates the policy and media discourse. The key beneficiary of this permeation is the 'what works' epistemology, in which policy initiatives become more evidence-based, the notion of 'fixing schools' (Lingenfelter, 2015) emerges along with promises of a pedagogical tweak to address every unsatisfactory outcome. Sayer (2020) attributes the rise of 'what works' in the 1990s to criticisms that education research lacked the rank and rigor of 'the more reliably truth-yielding qualities' of medical research. 'What works' at national policy level is necessarily predicated on certain assumptions. Firstly, that is it possible to discover what works. Secondly, that 'what works' can be usefully translated into teaching approaches that will result in improved pupil outcomes a high percentage of the time. Thirdly, that what works in one classroom will work in all classrooms. Fourthly, that education practice can be neatly compartmentalised ('what works' for special educational needs and disability -SEND-, for teaching reading, or teaching mathematics, or managing behaviour, or preventing radicalisation) without mutual-exclusivity or conflict of interest between policies. Understanding what does and does not work in education relies on our ability to make causal attributions (Koopmans, 2016). The first and second of the above assumptions are at the heart of the causality simplification issue, however, to repeat Byrne's (1998) assertion about the social world, 'outcomes are determined not by single causes but by multiple causes, and these causes may, and usually do, interact in a nonadditive fashion' (p.20). This and similar submissions from Geyer (2012), Mason (2016), Koopmans (2014; 2016), Morrison (2012) among others, suggest that even the idea of discovering 'what works' is an impossibility, since complex social systems, such as schools or the teaching and learning nexus within them, are highly contextual and do not behave in ways conducive to illumination via evidence from random controlled trials (RCTs). Identifying teaching practices which research indicates may accelerate pupil learning on average is one thing. To presume such practices will 'work' everywhere is probably expecting too much. RCTs may provide insights useful to policy makers, but that they are not the be-all and end-all. As Hardman (2010, p.8) suggests, 'policy makers would do well to recognise the limitations of their insights'. This presents a challenge to all of us researching teaching and learning, however. As discussed above, the urge to discover 'what works' is in-built in human beings and whilst many educational researchers are wary of the reductionism of RCT data, and sceptical of its generalisability, they nevertheless apply what might be termed a 'soft' 'what works' mindset. This mindset tends to be critical of prescriptive policy driven by political expediency and fuelled by quasi-experimental data, acknowledging the messiness of learning and the necessity of reflection and judgement from teachers. However, it also still presumes learning to be largely a product of teaching. As noted in section 2.3, most educational research is positioned this way to some extent, particularly that which seeks to make recommendations about 'best practice'.

The issue of causality and its appropriateness as a framework for determining teaching approaches has been thoroughly interrogated by complexivist educational researchers (Snyder, 2013; Jorg, 2009; Mason, 2009; Low, 2008; Davis and Sumara, 2005; Morrison, 2006; Doll, 2000). There is a consensus that complexity thinking and the 'what works' approach are somewhat incompatible because complexity theory is essentially descriptive, not prescriptive and to attempt pedagogical prescription using complexity thinking is to commit a category error (Morrison, 2006). One reason put forward for this is that complex systems are contextually grounded to the extent that one-size-fits-all policies, if insufficiently flexible, have limited potential. This point is articulated by Trombly (2014) (and explored more thoroughly in the following chapter) who states, 'Simple solutions imposed with no regard for schools' […] unique contexts hold little promise' (p.40).

2.6 Conclusion

This chapter has discussed assertions about the nature of learning and emphasised an apparent consensus that whilst learning takes various forms, including those which may and may not be considered educational, change is its defining characteristic. The literature on classroom and small group educational learning places social interaction as a necessary organising principle and antecedent of changes in individuals and collectives. The chapter has explored 'what works' evidence about how learning may be most effectively configured. Challenges to the concept (and goal) of 'effectiveness' in the context of small group classroom learning were presented, drawing on principles from complexity and tensions between 'what works' and complexity informed epistemologies discussed. I have framed interactive group work as an example of an enabling constraint, used by teachers to locate and occupy a middle ground between equally necessary sources of disruption and stability, which create space for interaction, counterpoint, perturbation and novelty whilst avoiding all-out chaos. The question of whether CAS principles offer useful points of reference for analysing small group learning was considered with the general conclusion that this depends on the dominant organising principles at work in classrooms.

The objective to present a more authentic portrait of teaching and learning which acknowledges its complexity was one of the motivations for undertaking this research. However, Cilliers (1998) argues that all representations of complex phenomena necessarily betray their object, suggesting that even deliberate attempts to illuminate the multivariate, distributed, self-organising facets of classroom teaching and learning will ultimately fall short. This insight is particularly pertinent to this study, serving as a useful reminder of the descriptive limits of complexity sensitive social research. The following chapter explores this and other methodological considerations underpinning this research.

3.0 Methodology

3.1 Introduction

The aim of this study was to identify aspects of primary classroom small group learning which could be characterised as emergent and to locate and describe some of the factors, including interactions, background knowledge, group/class dynamic and relationships, which contribute to this. As discussed in Chapter Two, learning is difficult to define, takes various forms, does not always surface predictably and can be difficult to identify. A starting presumption, therefore, was those factors contributing to bottom-up emergent learning are by nature tacit, subtle and therefore harder to pinpoint than top-down factors such as teacher explanation or demonstration and that the methodology would need to reflect this. Another presumption concerning the site for the research (a year 4 primary school class of 30 pupils) was that it would prove to be a dynamic research landscape demanding adaptive approaches. The study aimed to develop insights into a complex phenomenon within a shifting, changing environment whose 'components interact in multiple, non-linear ways...' (Poth, 2018, p.4) and the methodology reflected this. A secondary aim of the research was to evaluate the usefulness of CAS as a conceptual lens through which to analyse the learning and teaching nexus in a primary classroom.

The methodological framing of the study was a mixed-methods, complexity-sensitive case study, the phenomenon under scrutiny being classroom learning and the case, or bounded system (Gay, Mills and Airasian, 2009) being that of a single year 4 class. The following sections describe, explain and justify the research design used to glean insights about the nature of classroom learning, and the utility of CAS for describing classroom dynamics and their influence on the emergence of learning. This chapter begins with an overview of the conceptual framing of complexity thinking. Following this, ontological, epistemological and axiological underpinnings of the study are discussed before an overview of the research context and sample and discussion of the data collection methods are presented. This includes analysis and justification of my decisions concerning instrument selection, data gathering and arguments about reliability and validity.

3.2 The conceptual framing: Complex adaptive systems (CAS) and complexity thinking (CT).

Whilst descriptions in the literature of CAS properties overlap considerably, the lack of any unified complexity theory field of study, single body of literature, or agreed nomenclature has proved an impediment to achieving a universally applicable complexity framing in the social sciences. As Sullivan (2009, p.5) points out, ‘it seems every theorist has his or her own list of characteristics, qualifying properties, or optimal conditions for complex adaptive systems, each slightly different from the next’. Some have attempted to consolidate divergent definitions into more generalisable specifications for complex systems (Carmichael and Hadzikadic, 2019; Preiser *et al.*, 2018; Wilson, 2016; Sullivan, 2009; Holland, 2006, 1995), however, even in synthesised forms there is considerable divergence from one framing to the next. Davis and Sumara, (2006), Mason (2008), Morrison, (2008), Radford (2008), Sullivan (2009), Newell (2008), Hardman (2015, 2010) and Ricca (2012) among others have drawn on framings from complexity sciences to describe and discuss features of CAS in the field of education, though here too, no consensus exists about how to frame CAS. One of the challenges to consensus is that theorists select different categories of CAS criteria. For example, some select criteria defining how CASs behave, others select criteria describing conditions for CASs and some use a mixture of the two. Some criteria (e.g., non-linear) are both behaviours and conditions, depending on one’s interpretation. To cloud the issue further, some treat criteria as distinct which others treat as synonymous (e.g., self-organisation and emergence). Sullivan (2009) produced an overview of CAS definitions (see Appendix A) which illustrates this point. Whilst no two definitions align exactly, there are certain characteristics I deem to be most relevant to school classrooms which appear repeatedly, shown in Table 3.1. These formed the core complexity thinking (CT) framework for the analysis. Bullet-pointed under each criterion are corresponding classroom behaviours and phenomenon used as points of reference in the data analysis.

CAS criteria	Definition	Theorists
Self-organisation *observable phenomenon *interactive dynamics *pupil subcultures *spread of knowledge *imitative behaviours	organised patterns of synergistic behaviours which aggregate across the system	(Clarke & Collins, 2007; Mennin, 2007; Davis & Sumara, 2006, 2001, 1997; Livneh & Parker, 2005; Harkema, 2003; Carr-Chellman, 2000; Pines, 1998; Holland, 1995; Doll, 1989).
Emergence *Bottom-up behaviours *Bifurcations *Perturbations/injection of novelty *Unpredictability *Evidence of non-additive learning *Impulsive/instinctive behaviours *Local decision-making *Pupil autonomy *Well-networked interactions	phenomenon arising from the bottom-up within the system. Changes initiated locally rather than centrally	(Sullivan, 2009; Davis & Simmt, 2006; Davis & Sumara, 2006; Nelson, 2004; Harkema, 2003; Pines, 1998).
Non-linear *Causation networked *information moves back and forth between pupils *Pupils send and receive signals *positive/negative feedback loops	information moves between agents via feedback loops and signals, therefore causality is not linear but networked and recursive	(Sullivan, 2009; Mennin, 2007; Nelson, 2004; Harkema, 2003; Pines, 1998; Holland, 1995).

Transcend their components *Produce learning beyond knowledge/capabilities of each individual.	exhibit properties not manifest in individual agents; systems that learn; learning is more than the sum of the system parts	(Davis & Simmt, 2006, 2003; Davis & Sumara, 2001, 1997).

Table 3.1 CAS criteria selected to frame analysis.

This study was not inquiring whether a classroom is a CAS. This question has been discussed by some (Hardman, 2010, 2015; Sullivan, 2009) including me (Knight, *in press)* with mixed, but indefinite, conclusions which depend largely on the CAS definition used, and the classroom in question. I acknowledge that a primary classroom is not a CAS as originally conceived in the natural or computational sciences. The intention in this research was to investigate whether CAS-like characteristics are useful for developing otherwise tacit insights about the nature of classroom learning, therefore I have selected criteria I judge to be most applicable to a primary classroom to form a CT heuristic for the study. The qualities in Table 3.1 became points of reference for evaluating the ways, and extent to which, learning arose out of complex behaviours in the small group contexts.

3.3 Justification of the paradigm

3.3.1 Ontology and Epistemology

As stated in Chapter One, I am ontologically a complexivist, viewing the social world as a mixture of order and chaos which 'find their limits in each another' (Camus, 1953; p.291), and tend to view social phenomenon as likely to be more complex than they first appear. I describe the world largely on the terms in which I experience it, as a mixture of order and disorder, choosing not to treat these two as dichotomous. When considering social contexts, I assume there is more going on than meets the eye and am naturally suspicious of simple explanations. Traditional conceptions of epistemology are challenged by this position, suggesting as they do that complex problems, what can be known about them and ways of coming to know, are separate entities. The literature on research in complex social systems, however, suggests that what there is to know, and how one can know about it, can no longer be considered as distinct. Bousquet and Curtis (2011) for example, refer to the 'attraction' of a 'movement away from essentialist conceptions of physical and social objects towards relational and processual ontologies' (p.48) in which social reality is reframed as relational rather than unitary and reductive. Gioia (2003) on the other hand notes the growing vagueness of the distinction between the concepts of ontology and epistemology with exasperation. A traditional realist ontology, which assumes an independent reality existing prior to human cognition, and a distinct objective epistemology which seeks causal relationships in order to locate that reality, sit uncomfortably within complexity-sensitive research, wherein the nature of reality (ontology) is revealed through ways of knowing about it (epistemology). According to Allen and Varga (2007, p.19)

> 'If epistemology is about what we know and how we know what we know (what is inside) and ontology is about what there is to know (what is outside) then the most fundamental challenge that complexity makes is that these can no longer be considered as separable.'

They go on to posit that the traditional conceptions of ontology and epistemology have always been a problem in social research because 'situations are historically evolved, involving local, co-evolving contexts' which therefore 'can potentially all be unique and lacking in any generic behaviours or laws.' (p.19). This view from complexity science suggests that neither what can be known, or its knowledge objects, are sufficiently stable to be reliably assumed to exist or be built upon in contexts apart from those in which they emerged. What follows from this ‘emergentist epistemology’ (Osberg and Biesta, 2008, p.317) is that it is not possible to build an accurate picture of an external reality through repeated experimentation. According to Osberg, Biesta and Cilliers (2008) a complexity influenced reading of ontology and epistemology sees the two concepts as overlapping, interactive and emergent rather than distinct, mutually exclusive and stable.

This is not to deny the existence or relevance of causality in social research. Clearly effects in the social world have antecedents, just as actions and events have consequences and reality is relatively stable at any given moment. However, an ontological-epistemological position influenced by complexity conceptualises social causality as non-linear, meaning that the system changes over time and effects of events within a system are pluriform and felt at all levels of the system. A given effect can be the consequence of multiple interacting causes, and itself a cause of multiple effects. As Morrison (2012, p.15) puts it

> ‘recent developments in complexity theory both frustrate conventional approaches to understanding causation and suggest the need for new ways of looking at, and for, causation in social research.’

If, as Koopmans (2014, p.20) suggests, causality is ‘an inextricable part of the educational process’, it is necessary following Morrison’s (2012) suggestion, to consider what it looks like and how it can be identified in the context of a complexity sensitive classroom case study. The need to be able to decide ‘what works’ in the current education climate makes causal attribution vital at all levels of the system, from policy authors to head teachers to teachers, parents and of course pupils themselves. The ‘what works’ epistemological conundrum (discussed in Chapter Two) is also of vital importance to educational researchers

(Morrison, 2012), even those employing a paradigm which challenges linearity. The ontological-epistemological challenge for complexity sensitive researchers is identifying what can be known and what might actually cause what in the research moment. The ontology of this research was complex realist (Byrne and Callaghan, 2014; Byrne, 1998; Harvey and Reed, 1996), described by Harvey and Reed as situated somewhere between positivist and interpretivist approaches. Complex realism straddles the traditions of critical realism and complexity which have converged most notably in the work of Byrne and Uprichard (Byrne and Uprichard, 2012; Byrne ,1998) and Williams (2009; 2011; 2021) and emphasises the importance of a real-world grounding of research in contexts where outcomes are uncertain and variable. Byrne describes this as developing ‘useful empirical knowledge about social reality’ (Byrne, 2011, p.6). Williams and Dyer (2017) argue that a complex realism framing is suited to social research because ‘the reality of the social world is that it is indeterminate’, changing due to perturbations which may be best mapped over time. Combining aspects of critical realism and complexity theory into an ontological frame acknowledges that events in the social world are extremely variable and unpredictable, but not random or inexplicable. Causality can be investigated, and social phenomenon can become understood contingently, however linear causal frameworks are insufficient to understand the non-linear, probabilistic nature of social realities. Williams (2021) argues that complex realists must acknowledge the central role of probability in the social world, that events are never socially determined and therefore always probabilistic.

Bolster (1983) summarises the principal problem with applying an epistemology of linear causality to a social system such as a classroom:

> ‘. . . much social science research on teaching assumes that causation in classrooms

operates unilaterally from the teacher to the students . . . teaching is viewed exclusively in terms of the influence instructors have on pupils; the reciprocal effects of students on teachers or of students on students and then on teachers are thought to be either non-existent or not of central consequence' (p. 302).

A complex realist perspective, developing productive, empirical insights about social entities demands a focus on process and causality, but acknowledges causalities to be networked, interdependent, tacit and sometimes indeterminate. Larsen-Freeman (2016) articulates a similar point stating that in a complex system 'it is understood that it is highly unlikely that a single cause will give rise to a single effect' (p.380). Along with others (Biesta, 2009, 2016; Morrison, 2012; Jörg, 2009; Mason, 2008; and Davis, 2008) she posits that complexity frustrates realist understandings of causation because complex systems do not behave in ways conducive to linear causal analysis. The reality being researched, to the extent that it can be known, is current, not final.

The conception of causality adopted in this research was that learning is 'caused' directly and indirectly by multiple, interacting and situated factors which can be manipulated to increase the probability that learning will occur. My position is that social entities are real in the sense that we experience their effects every day, and knowable to some extent. However, I concur with Cartwright (2004) that attempting to capture the complexities of social entities within a linear causal framework is to chase rainbows. Discovering how factors interact with one another non-linearly demands a complexity-sensitive approach. I believe there are such things as effective and ineffective teaching, in the sense that some approaches have higher probability than others of invoking conditions conducive to learning (demonstrated by my broad framing of 'what works' in Chapter Two) but see causation as stochastic in this context and reject the idea that effective/ineffective can be too confidently generalised in education, other than at meso or macro levels of analysis. To be clear, I am not rejecting the idea that certain approaches may 'work' whilst others may not, but qualifying the notion with questions such as, work where? For whom? Under what conditions? When applied how? For how long?

3.3.2 Inter-relatedness of axiology and epistemology.

This study was axiologically motivated. A central axiom underpinning the project was that if something is worth problematising, it is worth understanding and describing as authentically as possible. Collins (2015) explains that a researcher's axiological positions influence their assumptions about what kind of questions are worth addressing and this was the case for the present study. My commitment to pupils' learning and to the teaching profession, both as a former primary school teacher and currently as an educator of future teachers, motivates me to develop greater insights about learning and teaching. However, this motivation also reveals how as a researcher I am straddling different epistemological and axiological camps. I have previously identified a tension that exists between the complex, networked nature of classroom interaction and the everyday 'what works' approach prevalent in teaching. I have also argued the case against a rigid causal interpretation of teaching and learning and in doing so acknowledge that this research was paradigmatically averse to epistemologies currently dominant in education. However, the act of undertaking this research is also, to an extent, a concession to 'what works.' For example, the stated aim of the education doctorate programme is to 'better understand and improve programmes of training and education and, through this, to improve professional services and their role in a democracy.' (HE Institution website, 2020). Discovering 'what works' is hardwired into the doctoral programme. Radford (2006) however, controversially advises that since analytical reductionist methodologies in educational research cannot deliver the type of information from which universally applicable policy can be derived, the central role of research should be to provide descriptions and explanations which can be used to inform situation-specific, local decision making. This stance is likely to be viewed as a compromise by those invested in the 'what works' policy project, and it is an assertion I have mixed feelings about. My values as a teacher committed to improving and widening education opportunities makes the 'what works' project attractive. However, as previously stated, I am instinctively cautious about assertions of quick, universally applicable fixes based on linear causal analysis. To paraphrase Biesta (2007) I acknowledge that 'what works' does not always work. For me, this is not just an epistemological position, it is also axiological. My position with respect to the 'what works' (and 'soft' 'what works') agendas is that they are inevitable products of the very human drive to improve, and therefore phenomena in which all of us involved in education are implicated. Important nuances are lost at the sharper end of politically-driven 'what works' policy-making, but at the softer end, where context is accounted for and teaching and learning are understood less mechanistically, more authentic depictions of classroom learning are possible. However, even this study, with its deliberate efforts to look for evidence of learning in new ways and in new places, makes recommendations for 'what might work' in practice. To paraphrase Wallace (2009) the 'what works' instinct is 'the water we swim in'.

3.4 Complexity-sensitive, mixed methods research (MMR) design.

Poth (2018) argues that MMR is well positioned to contribute to an understanding of systems where multiple known and unknown factors interact. According to Bazeley (2018), MMR is useful in exploring the 'wicked problems' and 'grand challenges' of the social world. Mertens *et al*., (2016, p.4) claim MMR researchers demand methods which are 'able to investigate a problem from multiple viewpoints, with flexibility to adapt to changing situations, yet able to produce credible results convincing to diverse audiences'. Bazeley (2008) further points out that since all phenomena inherently have both quality and quantity the value of research designs which capture both, including connections between them, speaks for itself. Arguments in favour of synthesising Social Network Analysis (SNA) data on interaction type and frequency with participants' qualitative explanations and reflections within a complex classroom context are compelling and therefore MMR was a good fit for this study. The following section makes the case for the complexity-sensitive, MMR design used.

There are strong arguments for the potential which MMR approaches have within social spheres to unlock insights into complex phenomenon. Poth (2018) argues that numbers and words can be powerful allies when co-ordinated successfully, the former demonstrating the presence, prevalence or significance of an idea, practice or trend and the latter delving into to it to better understand it. In the case of this study, in order to gain insights into how a (non-exhaustive) range of factors influencing learning tesselate with one another, an MMR approach seemed most appropriate, not least because it proved crucial to know not just what was going on and how frequently, but how and what the consequences were.

As explored in Chapter Two, successful learning is dependent on a wide range of interdependent factors, some more visible than others, some personal, some collective, some episodic and some continuous, but all interconnected and complex in their own right. When considering the complex interactions between these factors, the challenges of investigating their collective influence on learning comes into relief. To navigate the pluriform and messy (Sanscartier, 2020) nature of social contexts researchers must tackle the issue of causation. This presents a challenge due to the sheer volume of different concepts of causality presented in the MMR literature. If the mosaic of causal interactions affecting learning which play-out daily in a typical primary classroom warrants examination, it will need to be looked at from a variety of different angles and in a variety of different ways. According to Tashakkori, Johnson and Teddlie (2019) both qualitative and quantitative interpretations of causation are important in undertaking a defensible social enquiry. This strengthens the case for a MMR approach in this research, however as Day, Sammons and Gu (2008) point out, combining qualitative and quantitative data sources is not an antidote to what Uprichard and Dawny (2019) term 'capturing the mess' of the social context. Considering the challenges of designing research which can capture the 'mess', Law (2004) argues that the design itself will inevitably have a certain messiness, because 'simple, clear descriptions don't work if what they are describing is not very coherent itself. The very attempt to be clear just increases the mess' (p.2).

Chapter Two explored arguments that the classroom teaching-learning nexus is a complex balance between coherence and disorder, only partially knowable, at least at the resolution commonly employed by those attempting to describe it. Law (2004) strikes a somewhat pessimistic note when discussing the possibility of describing or coming to 'know' about complex phenomena, stating 'if much of reality is ephemeral and elusive, then we cannot expect single answers. If the world is complex and messy, then at least some of the time we're going to have to give up on simplicities' (p.2). He presents three broad responses to this potential roadblock in social science research. Either researchers need to explore new ways of knowing (embodiment of experience, knowing through emotions or intuitions), or recalibrate expectations about the applicability of what is known (how far can it travel or the extent to which knowing brings phenomena into being), or both. Either, or both, of these suggestions requires researchers to exercise creativity, courage, flexibility and a willingness to break with established methods to some extent. Hunter and Brewer (2015, p.185) share the view that social science research should break from convention when examining complex systems. They distance themselves from the idea of formulaic, codified or sequential 'cookbook' approaches to multimethod design, arguing that to expect 'do[ing] A then B and combining with C to produce […] an optimal outcome of research findings' is not only unrealistic, but undesirable. They prefer to conceive multimethod research design as an art which, whilst requiring advance planning, can just as easily be developed post hoc through pattern seeking, pragmatism, adaptation and evolution. The degree of advance planning in this equation might be dictated by the complexity of the system or phenomenon under study. In the case of this research, the complexity of both the phenomenon and the system warranted a balance of planning and 'art'.

3.4.1 The issue of integration

Central to successful mixed methods design is meaningful integration of data sets. In fact, a reading of the MMR literature suggests that how data sets will be integrated, how one set will speak to the other and how they will confirm or contradict one another is the dominant preoccupation of the MMR community. Successful integration is regularly cited as the key strength of successful MMR studies, and the key weakness in those deemed less successful. Key integration questions are: what exactly is being mixed? When in the process does the mixing occur and with what emphasis (Åkerblad, Seppänen-Järvelä and Haapakoski, 2020)? The 'when' question has preoccupied several MM researchers. Day, Sammons and Gu (2008) consider it a flaw in MMR if quantitative and qualitative results are designed separately and only mixed towards the end, positing that it is preferable to allow different forms of data to interact with one another through the data gathering process. Poth (2018) also supports the view that it is optimal for the research design to take account of integration from the outset. Whenever integration occurs however, there is widespread agreement that the consequence of integrating data sets should include insights which are more than the sum of the individual parts and which could not have been derived without the integration (Bazeley, 2018; Fetters and Molina-Azorin, 2017; Sandelowski, 2014; Leech and Onwuegbuzi, 2009). Data in this study were selected with integration in mind. Plans for integration began long before data collection and were further aided by initial piloting and review. Decisions concerning the form and scope of data sets continued throughout the data collection itself in response to changing circumstances and judgements about complementary qualities and possibilities for integration. Researcher field notes were also informed by in-situ integration of data sets. These iterations are described in Section 3.7 below. Details about data integration at analysis stage are presented in Chapter Five.

3.5 Complexity-sensitive case study

A study framed theoretically in relation to complexity thinking (CT) aiming to investigate a classroom as a complex adaptive system (CAS), lent itself to a case study methodology. The (albeit ambiguously) bounded nature of CASs and the common depiction of case study as a method of studying bounded systems or entities (O'Leary, 2010; Creswell, 2008) made compatibility between the conceptual and methodological framings clear. Stake (2006, p.2) points out that the 'first objective of a case study is to understand the case'. Elaborating on this, Thomas (2009, p.115) describes case study as 'in-depth research into one or a small set of cases' the aim of which is 'to gain a rich, detailed understanding of the case by examining aspects of it in detail.' Punch (1998, p.150) emphasises that a researcher's intention when using case study design should be to gain 'as full an understanding as possible' about the case. This emphasis on gaining thorough understandings is also highlighted by Cresswell (2008, p.476) who also uses the term 'in-depth' to describe case study inquiry. The principal aim of this study, and a key justification for the use of case study methodology, was to gain insights into a classroom phenomenon (pupil and class learning from sources of bottom-up, emergence, rather than top-down teacher instruction) which is largely invisible to observation. Case study, with its underscoring depth and particularity (Gay, Mills and Airasian, 2009) offered the best possibility of achieving this aim. The potential for developing meticulous understandings of a system is a central advantage of case study methodology in qualitative research, which 'owes its legitimacy to the experiential knowledge of phronesis, rather than the generalising power of induction (…), explanation and prediction.' (Thomas, 2010, p.575). However, the depth over breadth approach is not without its critics.

Critiques of case study have ranged from its inability to produce insights about the broader class generalisation (Abercrombie, Turner and Hill, 1984) and the prowess of theoretical knowledge over practical knowledge (Campbell and Stanley, 1966) to concerns about reliability and validity (Tight, 2010) and verification bias (Diamond, 1996). Flyvbjerg (2006, p.241) among others has addressed these concerns by arguing that social science research is problem focussed, not methodology focussed, and that case study is a 'necessary and sufficient method' for generating knowledge about certain types of problems. Even within a broadly interpretivist framework a case can be made for generalisability of case study findings. Abercrombie, Turner and Hill's (1984) charge that case study findings cannot produce insights about the broader class depend to some degree on commonalities between the case and all other cases in its class. Structural and organisational similarities between key stage two classrooms nationwide (curriculum, timetabling, physical space, pupil ages, common teaching and assessment practices) enhance the generalisability of insights generated in one such classroom, albeit not to the extent of quasi-experimental research. Haggis (2008) reinforces this point, stating that

> ‘Clearly, some kind of connection between the results of a case study and other potential situations is possible, but these connections are subtle, interpretive, and to some degree speculative.’ (p.155)

I did not seek to make water-tight, widely applicable generalisations relevant to all other key stage two classrooms, however broad recommendations applicable beyond the specific case and theory development were anticipated and are made in Chapter Nine. Verschuren’s (2003, p.137) representation of case study is perhaps most pertinent to this research

> ‘A case study is a research strategy that can be qualified as holistic in nature, (…) explicitly avoiding (all variants of) tunnel vision, (…) and aimed at description and explanation of complex and entangled group attributes, patterns, structures or processes.’

Of particular note is his reference to the ‘holistic nature’ and ‘explicit avoidance of tunnel vision’, which correlate with previously presented depictions of case study as detailed and in-depth. The suggestion case study is well suited to describing and explaining ‘complex and entangled’ features of a bounded system makes it well-matched with the aims of this study. By examining learning in small groups, nested within the classroom system, the intention was to avoid what Cilliers (1998, p.2) describes as ‘cutting up’ the system and thereby destroying though analysis what one is seeking to understand.

3.5.1 Complexity-sensitivity

Hetherington (2013, p.72) posits that in research which adopts an explicit complexity framing, 'complexity theory should inform both the framing of the research problem and the methodological choices (…)'. This means that the research design and data gathering instruments should be chosen, or created, with conditions of complexity in mind. Complexity-sensitive research is described by Poth (2018) as approaches which adapt to evolving conditions inherent to CAS. Perhaps the most significant of these conditions, and the ones which most demand researcher responsiveness, innovation and in-situ consideration, are agent connectivity and emergence. In the context of a primary classroom these are seen in the myriad of moment by moment shifting interactions across all levels (dyads, triads, table groups, whole class) and the unpredictability of associated events and phenomena. According to Poth (2018, p.58), sensitivity to shifting conditions enables adaptive practices in which the researcher 'dynamically adapts to the constantly changing research environments (…)'. The case study classroom presented a multitude of shifting conditions, my responses to which are described in Section 3.7.1. Hetherington (2013) argues that case study is an ideal instrument for researching complex systems because it 'enables the researcher to balance the open-ended, non-linear sensitivities of complexity thinking with the reduction in complexity, inherent in making methodological choices.' (p.71).

In defining the CAS (small groups nested within a primary classroom) which would be the object of study, the case was also automatically defined. In considering behaviour, organisation and change within the classroom, the phenomenon under study (emergence of learning) was also automatically defined. As described in Chapter Two, complexity reduction practices are common in schools, but research itself also imposes constraints on system complexity via the necessity to define research boundaries and the impossibility of researching every aspect of a system. In this research complexity reduction occurred to a certain extent due to complexity-reduction mechanisms common to all schools (timetabling, compartmentalisation of curriculum, pupil organisation), but also as a consequence of researcher choices. Biesta (2010, p.7) describes complexity reduction in terms of '(a) reducing the number of options for action for elements within a system; and (b) impacting on the recursion within the system by constraining the language used in the system'. In this study, researcher choices corresponded with point a) above. For example, the decision to prioritise, capture and analyse predominantly small-group interactions within the classroom system, the decision to ask pupils themselves to report on moments of learning and the decision not to interview every pupil in the class support Hetherington's (2013) assertion that case study invites complexity-sensitive researchers to both acknowledge and manage complex system conditions.

3.6 Context of the study

The study took place over one week of the summer term in the year 4 class of the school. The 'research week' took the form of a week-long class project in which pupils, working as a whole class and in small groups, learned about, designed, made and tested model rockets. Having suggested this theme and discussed its suitability with the teacher (referred to throughout as 'the teacher'), I stepped back and the teacher, who was newly qualified and near the end of his first year in the profession, planned and facilitated all activities during the week. I planned and undertook the range of research activities, including observations, pupil self-reporting of 'moments of learning' (MoL), one-to-one pupil interviews and filming of whole class and small group interactivity. In addition to this, I kept daily observational field notes (data collection is explained fully in Section 7.3). I gave practical support to the rocket testing since I had constructed and supplied the rocket launchers for the project.

The school was one with whom the university had an ongoing partnership, though I had no prior personal or professional connection to the institution itself. The year 4 class was nominated to participate by the head teacher and whilst I had no known connection to the class teacher initially, I later discovered that he had obtained his post graduate certificate of education (PGCE) at my university. The teacher-researcher dynamic and its influence on the research week is explored more thoroughly in Chapter Four.

3.6.1 The research environment and sample: The class and the classroom

The year 4 class consisted of 30 pupils (16 male and 14 female) aged between 8 and 9 years, one class teacher and one learning support assistant (LSA). The pupils represented a range of ethnic, cultural and national backgrounds, including British Asian (3), Black British (2), Mixed race British (7) White Canadian (1) and White Polish (1). The largest ethnic and cultural group were White British (16). Whilst not pertinent to the research itself, the cultural backgrounds of the pupils is one element introducing diversity (see Chapters Two and Seven) into the classroom system. Other pupil characteristics contributing to system diversity, alongside sex and ethnicity/culture, were socio-economic circumstances, special educational needs and disabilities (SEND) and language. Of the 30 pupils in the class, three came from homes within an income bracket which entitled them to free school meals. There were four pupils on the class SEND register, three of whom had recognised learning difficulties and one of whom had significant social and emotional behavioural difficulties (SEBD). There were three pupils for whom English was not a first language and whilst all three spoke English with degrees of confidence and fluency, reading and writing presented increased challenges for two of them. Data was collected from all pupils. The decision to limit the sample to a single class was partly guided by the head teacher who specifically nominated this class to participate, and partly by research design since the single class represented a bounded system, nested within the larger system of the school and was therefore ideal for CAS analysis. The single year 4 class therefore represented both a convenience and non-probability, purposive sample. Since, as previously stated, there are considerable structural and organisational commonalities between all key stage 2 classes nationally, the single class sample was also (speculatively) representative of the wider research population, to an extent.

3.6.2 Overview of the research week

I met twice with the class teacher a few months prior to introduce the research aims, describe and discuss the conceptual framing for the study, plan a framework for achieving the aims and discuss how this might be realised, including who would take responsibility for what. The proposed framework for the research week activities included three broad pedagogical pre-requisites intended to maximise CAS-like characteristics of the classroom:

1. Activities and goals needed to be sufficiently structured to produce coherence, but sufficiently open encourage emergence (a balance of freedom and constraint).
2. The teacher should (as much as possible) take the role of facilitator, encouraging independence and transferring agency and responsibility to pupils.
3. The week's activities should not be fully planned in advance but guided iteratively each day in consultation with pupils.

Having agreed upon rocket designing and making as the theme, the teacher used the intervening weeks to plan an overarching but flexible structure for the research week. Establishing in advance a clear division of labour was important for the smooth-running of the week, maximising data gathering, ensuring value for the pupils and maintenance of a positive working relationship between the teacher and me. Whilst insisting on the above pedagogical pre-requisites and noting my considerable prior experience as a primary school teacher (including several years teaching year 4), it was essential that once the research week began, the teacher taught, and I researched. It was agreed that he should exercise full autonomy over the running of the project, making decisions about all elements which would fall under the usual remit of a class teacher, including adapting pedagogical approaches as he judged appropriate. My role would be largely passive in respect of the teaching and facilitating of the activities. Establishing from the outset the dynamic that it was his classroom in which I was a visitor, was important. This agreement meant that once the research week began, I had limited influence over the maintenance of the pedagogical pre-requisites, which were (perhaps inevitably) compromised to a degree. This theme is discussed further in Chapter Four.

I made three preliminary visits to the school prior to the research week, during which I introduced the research project to pupils, sought pupils' consent to participate (see Chapter Four for a discussion of consent and assent) and took the role of a classroom assistant, supporting and talking to pupils. These visits enabled me to develop a rapport with the teacher and the pupils and to familiarise myself with the research environment, as Anderson *et al.*, (2005) point out, understanding a complex system requires prolonged engagement with the system. Preliminary research activities included mapping of the physical environment, developing insights into the relational dynamics of the classroom, assessing sources and balances of coherence and disruption (Davis and Sumara, 2006) and beginning to plan procedures for data gathering based on these insights. During the second preliminary visit I tested procedures for capturing video data, familiarising myself with the school's in-house video monitoring hardware and software, trying out different camera angles, establishing sound capabilities and learning about video storage and access. Between the second preliminary visit and the beginning of the research week the teacher piloted procedures for gathering pupil-reported ‘moments of learning’ (MoL) data. He subsequently sent me the pilot data with an evaluative overview. This enabled me to trouble-shoot and fine tune this method (a process which continued through the research week), including planning how it would be introduced and explained to pupils and integrated with other data sets. The research week itself ran from Monday to Friday. Each day the pupils collaborated in groups of four or five on a range of activities relating to the overall task of designing, constructing, testing and finalising prototype plastic bottle rockets. The teacher and I consulted multiple times through each day about project and research activities, ensuring alignment so that project activities did not disrupt data gathering and vice versa. These often took the form of the teacher checking that pedagogical approaches and classroom activities were fulfilling the pedagogical pre-requisites for the study and me checking suitable times and locations for collecting data.

Each pupil group was mixed sex and mixed attainment (based on English, Mathematics and Science teacher assessments) and each was designated a famous astronaut as its mascot. Whilst each team had their own workstation, movement of pupils was not restricted, resulting in a significant degree of inter-team interaction throughout the week. Each day began with a class briefing in which the teacher summarised achievements from the previous day and discussed milestones for the present day, along with the schedule of fixed events (e.g. morning break, lunch break, assembly). The teacher also gave advice about cooperative working, explained rules for use of the rocket launchers for testing, made suggestions about steps to consider through the day and explained any necessary productivity milestones in order to keep each team on track for completion by the end of the week. Within these frameworks each group was encouraged to exercise autonomy over its activities and the division of labour. Morning briefings also enabled me to recap research procedures for the pupils, including protocols for self-reporting ‘moments of learning’ (MoL) and reminders to ignore video equipment in the classroom, and to answer pupils’ questions. Whilst pupils worked on their project activities the teacher acted principally in the role of facilitator, troubleshooting, responding to queries, scaffolding activities and managing pupil behaviour in order to maintain a calm, cooperative classroom atmosphere. This frequently necessitated intervention at individual, group and whole class levels. Whilst pupils were engaged in their various project activities, I collected data.

3.7 Data collection methods

Present in both the planning and ‘art’ (Hunter and Brewer, 2015) of the research design were efforts to select methods which elicited useful and complementary data and integrate them effectively to address the research questions. Acknowledging Hunter and Brewer’s (2015) point about not seeking off the shelf research recipes, it was important to plan in advance, judge in situ and reflect retrospectively, how the various data elicited could be usefully integrated in order that they would illuminate more than the sum of their parts. Daily data sources captured during the research week included:

1. Pupil self-reported moments of learning (MoL)
2. Video observation of whole class and small group interaction
3. Researcher observational field notes
4. Individual pupil interviews

Figure 3.1 shows a timeline illustrating how data source were collected concurrently and points of data interface during analysis.

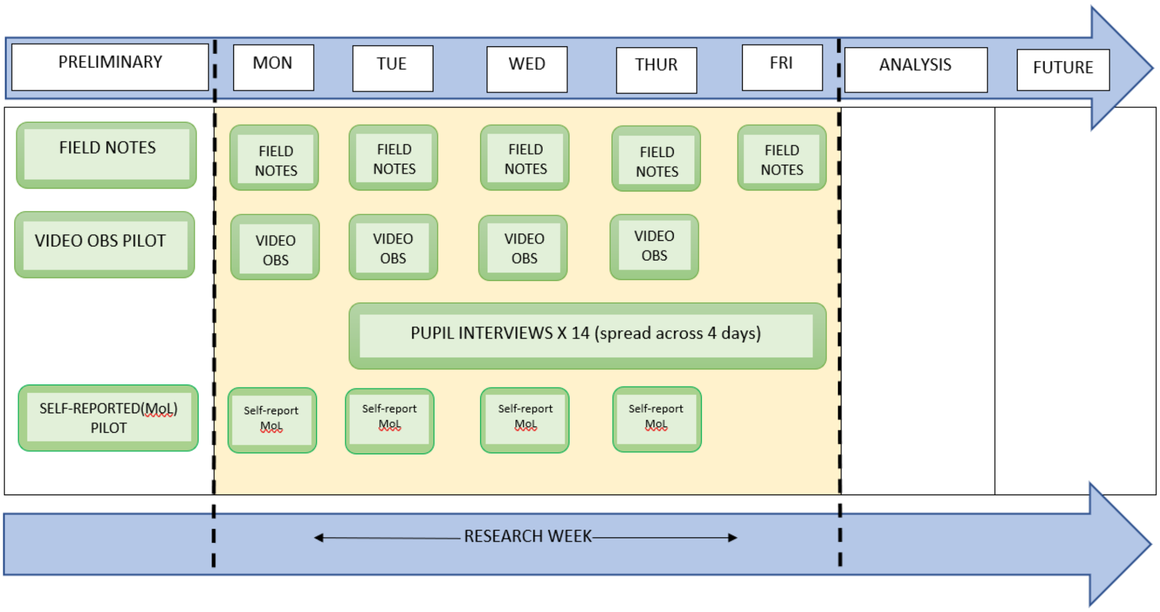


Figure 3.1 Timeline of concurrent data gathering and data interface during analysis.

3.7.1 Pupil self-identified moments of learning (MoL)

MoL were captured via a self-reporting system which ran throughout the week. Pupils were given sets of large post-it notes (Appendix B) on which to identify and categorise incidents of learning. Information on each note included pupil name, date/time, a tick-box choice of three categories of learning (realisation/knowledge/skill) and a space to describe the moment of learning itself. A blank area of wall in the classroom (the ‘learning wall’) was designated for pupils to stick their annotated notes throughout each day. Whenever a pupil judged that they had learned something they could identify and describe they were free to annotate a MoL note and stick on the learning wall. This data capture method was introduced and explained to pupils in a pre-research week pilot, when pupils rehearsed the procedure. Between 35 and 50 MoL were identified by pupils on each of Monday to Thursday during the research week. MoL notes were counted, recorded and briefly reviewed and collected at the end of each day (Monday-Thursday).

Considerable planning and thought lay behind this data capture method and it necessitated considerable explanation, introduction and reiteration for the pupils. Firstly, the decision of how to classify types of learning. As previously discussed in Chapter Two, learning does not occur in discrete packages nor are the antecedents of learning linear, singular or easily isolatable. To attempt to encapsulate the emergence of individual learning in all its possible forms within three discrete categories appears inadequate. Secondly, learning is often virtually imperceptible (Alexander, Shallert and Reynolds 2009) and pupils themselves may not possess the necessary metacognitive skills to identify their learning, its causes or processes (Kornell and Hausman, 2017; Finn and Metcalfe, 2014; Metcalfe and Finn, 2013; Dunlosky and Metcalfe, 2009). Thirdly, in view of the imperceptibility of some learning and the characteristic that it is only identifiable after the event (Biesta, 2009), even pupil self-reported data was likely to be error-strewn and incomplete. Thirdly, pupils' independent writing capabilities varied considerably, from fluent and accurate to limited and only partially comprehensible. In weighing-up these legitimate drawbacks however, I judged that, considering the alternatives (researcher or teacher observation), on balance the most authentic and practical means of capturing data on incidents of learning was to rely on pupil self-reporting. Since no system actor (pupil, teacher, researcher) had comprehensive access to insights about incidents of individual learning, the least bad option was to ask pupils to self-report. Constraints, compromise and dilemmas such as this are characteristic of social research in complex contexts according to Connell, Lynch and Waring (2001) and Brown (2010). Having decided on this approach, it was necessary to devise an accessible means for pupils to describe the learning upon which they were reporting. The categories of 'understanding', 'knowledge' and 'skill' were selected because of their common use as organising principles in successive primary National Curricula (DfEE, 1999; DfE, 2014) and among researchers (Wray, 2014; Kelly, 2014; MacBlain, 2014; Pollard, 2009). The term ‘understanding’ was replaced by the term ‘realisation’ because I considered it to be more accessible to year 4 pupils. Acknowledging that learning could be characterised by one, two or all three of these categories, flexibility was built into the reporting procedure allowing pupils to designate their MoL as a realisation, a piece of knowledge, a skill or any combination of these. Another challenge was supporting pupils in understanding these categories of learning sufficiently to enable them to make judgements about their learning. This required several cycles of explanation, rehearsal and review which took place predominantly during the pilot, but also continued in an iterative way during the research week itself. Pupils required regular reminders to use the MoL procedure when they became absorbed in project activities and occasional prompts that learning they shared with the teacher, the LSA or me ought to be captured on the ‘learning wall’. This data gathering method became increasingly refined throughout the week as the processes of meta-reflection and description of learning became internalised by pupils. Nevertheless, even by the end of the week there were a small number of miscategorised and anomalous MoL designations as a result of either misunderstanding, mistake or incomplete annotations. This demonstrated that although pupils became increasingly adept at using the process, it was still a work in progress for some towards the end of the week. To maximise the likelihood of reliable identification of MoL, time was spent during the pilot and the research week discussing what learning looks and feels like, how it is evidenced and ways of knowing what has been learned, including incremental and larger, novel leaps. To prevent the issue of limited independent writing skills prohibiting some pupils from articulating their learning, adult scribing support was permanently available to pupils. I checked the Learning Wall periodically each day to identify MoL post-its which were unclear or poorly explained and asked relevant pupils to ‘tell me more’ and offered to scribe where appropriate. Whole class MoL data did not form part of the analysis, but are tabulated and presented for interest in Appendix C.

3.7.2 Video observation of whole class and small group interaction

Social Network Analysis (SNA) data is commonly gathered by asking agents within a system to indicate on a survey the individuals within the network with whom they interact. This data is then graphed or tabulated. A limitation with this approach is that whilst the resulting data shows who is interacting with whom and how, it does not provide insights into the quality of interactions or how interaction form antecedents for qualitative emergent phenomenon such as individual or group learning. To avoid this constraint, similarly to Pomian *et al.,* (2017), I chose the novel approach of eliciting network interactions via video capture, following the suggestion from Sellers (2009) that video data allows children's activities, not just their words, to do more of the talking. Video observations took the form of predominantly small group and some whole class episodes of between 5 and 30 minutes. The IRIS system, which uses hand-held tablets and smart microphones to capture classroom activity and store footage on a central server, was employed due to the school already owning all necessary equipment for its internal monitoring of teaching. Throughout each day of the research week, I made in-situ decisions about which interactive episodes to capture. This involved observing the classroom system and positioning tablets and microphones advantageously to capture interactions. With two sets of recording equipment available it was possible to capture two interactive episodes simultaneously. Some small group activity was filmed simultaneously from two different angles to ensure that each group member was captured adequately.

Judgements were made about which episodes to capture based on the following criteria: a) most or all group members present and participating, b) interaction evident, c) collaboration evident. Due to the portability of the equipment, it was also easy to switch between recording one group and another simply by shifting the position of the tripods and microphones. This enabled me to respond swiftly to changing dynamics and shifting interactivity within the classroom and capture multiple interactive episodes per hour.

3.7.3 Researcher observational field notes (see Appendix D for example)

Following my initial meeting with the teacher, continuing during the pilot visits and extending throughout the research week, I made field notes about a range of classroom system dynamics. These included observations about the physical environment, its use and ways in which it shaped interactions; about the influence of the teacher on the pupils; about degrees of freedom and constraint within which pupils operated; about features of the class zone and their comparability to features of CASs and about my own positionality and influence as an actor within the system. The purpose of these field notes was to capture system level relationships, causalities, emergent phenomenon and evidence of factors influencing learning which might not be represented in the other data streams. Field notes acted as a processing mechanism enabling me to both record and begin to probe what I was noticing. This shaped decisions I took during the course of each day, including what footage to capture, where to position myself physically, when pupils needed reminders about research procedures, which pupils to interview, what interview questions to ask and how data sets might influence one another. Entries were written under headings of the relevant day and date, and under the following subheading: Complex adaptive system (CAS); Moments of learning (MoL); Procedural features (referring to researcher procedures and their adaptations); Researcher positionality and influence; Other and Review of the day. Field notes mostly took the form of bullet-pointed sentences, however within each of these sections I also wrote occasional vignettes, lengthier observations and researcher reflections.

3.7.4 Individual pupil interviews

Individual pupil interviews were conducted throughout Tuesday to Friday of the research week. Interviews took place in a room adjacent to the class zone, were one to one and lasted approximately 15-20 minutes each (see Appendix E). The purpose of the interviews was to invite pupils to elaborate on specific MoL they had previously identified and added to the learning wall (either that day or the day before). Each interview began by asking pupils to re-read their MoL post-it note(s) and recall the situation in which they identified the particular learning. Questions then invited them to reflect in more detail about the moment(s), including what happened in the build-up and aftermath, to glean understandings about in-class antecedents and consequences of each MoL. Questions followed about whether the MoL was also influenced by circumstances outside of the classroom or the school to help understand contributions from external circumstances. Finally, pupils were asked about their experiences of learning more generally by completing sentences such as 'I tend to learn best when….' and 'I find it difficult to learn when…' Fourteen individual interviews were conducted over four days. Sample selection for interview was based on:

- MoL – selecting a variety of learning types (knowledge, skills, realisations), prioritising MoL notes which were clearly articulated and unambiguous.
- Pupils – selecting a range of pupils from different small groups.
- Overlap with video capture – selecting MoL which were also captured on video for purposes of analysis.

Interviews were videoed using the IRIS system.

3.7.5 Responsiveness to shifting conditions

As discussed in Section 3.5.1, complexity-sensitive research demands in-the-moment responses to the dynamic research environment (Poth, 2018). Examples of conditions which shifted and required adaptive responsiveness during the research week were, the changing school or class time table which affected when rocket designing/building could take place; the presence or absence of pupils through the week which affected small group dynamics and the timing of interviews; breakages and maintenance of the rocket launchers and changing weather which delayed rocket testing and technical problems affecting the IRIS recording hardware or software influencing when and how it could be used. In addition to these concrete examples, there were a range of more subtle, relational factors whose shifts demanded adaptive practices. For example, the general atmosphere and mood in the class, levels of cooperation between pupils, moments of discovery or questions raised, all of which influenced decisions about what data to capture, when, where and from which sources. It is noteworthy that whilst many adaptive practices were in response to unforeseen challenges, a minority were precipitated by unforeseen opportunities and innovation. An example of this occurred halfway through the week when I noticed that some pupils had begun to include metacognitive annotations on their MoL post-it notes, presenting realisations they had had about their own learning. I judged that this was a welcome innovation (perhaps arising from misunderstandings about how to annotate the post-it note) and invited all pupils to do this if they had insights about their own learning. Table 3.2 summarises adaptive practices and their antecedents.

Dynamic conditions	Consequences	Adaptive practices
System factors *Events rescheduled unexpectedly *School assembly overrunning	Not able to undertake data gathering at planned/anticipated time Not able to undertake data gathering with planned/anticipated participants Pupil activities lag behind planned data gathering schedule	Last minute rearranging/rescheduling Deferring data gathering methods Adapting data gathering methods Abandoning data gathering methods

*Unpredictable availability of interview rooms/spaces *Pupil activities overrunning *Fluctuating noise levels	Occasional use of noisy or occupied spaces for interview purposes Difficulty picking up individual voices on recording	Adapted preparation of pupils for interview Adapted technical setup Small group video capture moved to quiet location (outside of class zone)
Proximal system factors *Unpredicted weather conditions (very windy) *Influences from media *Influences from the home	Not able to undertake data gathering at planned/anticipated time Changes in class mood Filming decisions influenced by pupil inspiration arising from TV programmes during research week Pupil lateness/absences Parents professionally involved in aircraft design Prior knowledge from family visits to aerospace museum influencing small group hierarchies	Rescheduling/reconfiguring of activity and data gathering On the spot decisions to film certain small groups Dialogue with pupils Suggesting pupils to create MoL note
Technical factors *Damage to rocket launchers *Issues with IRIS software/hardware *Limits of IRIS system capabilities	Delays in data gathering Failure to capture data	Rescheduling/reconfiguring of activity and data gathering Film one (rather than two) table at a time Trial and error with camera positions
Relational/human factors *Changes in class mood *Pupil emotional states *Discord between pupils *Behavioural disruptions *Presence of the teacher *Pupil autonomy	Influencing when video and interview data captured Influencing pupil interview selection and timings Higher/lower pupil productivity levels Greater/less pupil participation in MoL data process Fluctuating levels of pupil-pupil interactivity Varying degrees of procedural understanding from pupils Increased disputational/antagonistic pupil interactions	Delaying/rescheduling data gathering Judgements about which pupils to select for interview, and when Recapping MoL procedures to whole class Suggesting MoL notes to individual pupils at critical incidents Adapting data gathering schedule Revised introduction to group video capture – reminders about cooperation Judgements about duration of group video capture episodes

*Pedagogical negotiations with teacher *Novelty of MoL procedures *Pupil awareness of video recording equipment *Researcher presence/proximity	Pupil questions/spontaneous researcher interactions with pupils Pupils return to ‘on-task’ (desired) behaviours/activities Self-consciousness/acting-up for camera	
Other *Pupil innovation	Pupils suggesting adaptations to data gathering procedures Innovation arising from pupils not following designated procedures	Including (unanticipated) metacognitive category in MoL data Allowing collaborative MoL post-it notes Learning and adapting protocols in light of pupil feedback

Table 3.2 Summary of adaptive practices during the research week (managing ‘messiness’)

Data integration also influenced adaptive decisions about data collection throughout the research week. The intention to align and triangulate video observation data with MoL and interview data in analysis required a degree of logistical planning and considerable flexibility. Ensuring that MoL data were captured on video, that learning captured on video was also articulated in MoL data and that the relevant pupils were also identified and available for interview required me to balance judgements about capturing as much footage from different small groups as possible, against remaining vigilant to critical incidents which emerged. This sometimes meant moving the camera between multiple areas of the classroom without stopping recording. Exercising moment by moment judgements about the most useful episodes to capture, whilst also aiming to adhere to a daily data capture plan (drawn-up each evening after school and reviewed every morning upon arriving at school), meant that the resulting video was the consequence of both planning and adaptive practice. Shuck and Kearney (2006) argue that video data are as prone to subjectivity through selection as non-video-based data. They point out that decisions about what to record and how to record it are not neutral. For this reason, I established the previously described clear and justifiable criterion for what to capture.

Field notes made throughout each day provided the basis for the daily data capture plan, including decisions about where to position myself physically, what to film and who to interview. Poth (2018) describes this kind of reflective researcher thinking as integrative. According to Douglas (1994) integrative thinking involves the integration of multiple faculties, including reason, imagination and intuition to develop strategy, tactics, action and evaluation in any given situation. Poth (2018, p.75) recommends integrative thinking about data procedures in order to realise 'agile integrations' of data sets during data gathering. This accurately describes my moment-by-moment response to the various dilemmas I faced. Douglas' description of integrating strategy and tactics is also relevant here. Each day I strategized about next steps in data gathering, but strategies were always subject to in-situ tactical adaptations. Sanscartier (2020, p.48) describes this as 'design-related mess' and discusses how mixed methods researchers in complex and dynamic fields navigate the messiness by 'recursively and continuously modify[ing] research designs to fit the demands of diverse contexts […]' (p.47). Table 3.3 gives examples of relationships between integration decisions and adaptive practices.

Data integration decisions	**Adaptive practices**
Analyse individual learning episodes described on MoL notes against video of relevant episodes *(triangulation of self-reported learning with video capture)*	Vigilant to potential critical incidents occurring Readiness to relocate recording equipment quickly Prompting pupils to reflect on whether / what learning may have occurred
Analyse individual interview reflections on MoL against video of relevant episodes *(triangulation of pupil reflections on MoL with video capture)*	Regular checking of 'Learning Wall' and matching of MoL to individual pupils Daily reading and reflection (after school) on MoL notes from the day Evolving decisions about who to interview

	Negotiations about when to interview selected individuals Researcher journal always to-hand. Regular entries and reminders

Table 3.3 Influence of data integration on adaptive practices

3.8 Validity and reliability

Though validity and reliability are defined with wide variability by different researchers, (Cohen, Manion and Morrison, 2017) there is some consensus in the literature that validity refers broadly to the accuracy of data measure and that reliability, as a necessary condition for validity, is an umbrella term referring to dependability and repeatability of a measure. Several validity and reliability challenges were presented in the present study, mostly due to the complex and dynamic nature of the research context and the tacit nature of learning. For example, the dynamic nature and content of small group activities meant that no two episodes of video captured group work were very similar. In addition, insights about what pupils learned, when and how were typically only partially accessible, even to children themselves, meaning it was difficult to be confident that such data offered accurate representations. In the next section, three principal validity concerns and one principle reliability concern are set out, with explanations of mitigating steps taken.

3.8.1 Non-naturalistic research context

The research week was deliberately structured and configured to occasion emergence (Davis and Simmt, 2003), meaning that features of the classroom activity from which the data was collected were not typical or fully authentic for this classroom. The main structural design novelty was that pupils worked on the same project every day, all week, instead of different curriculum subjects each day. Another variation instigated for the purposes of the research was that pupils were given higher than usual degrees of autonomy over their activities. As such, they had significantly more ‘say’ in what they did and when and how they did it. This had the effect of giving pupils greater than usual freedom of movement within the classroom too. These novelties were intended to inject sufficient freedom to encourage emergence so that these effects could be captured in the data.

The threat to validity here was that phenomenon being captured and analysed would be inauthentic with respect to this classroom and school context; that something non-naturalistic was being occasioned to suit the research aims and that the resulting data would yield correspondingly inauthentic results. This could be viewed as a methodological weakness in the research design. However, it could also be argued that engineering conditions most conducive to emergent learning was the only realistic way of gaining insights about relationships between teaching and learning structures, emergence and self-organisation. The approach was also considered justifiable because not all classrooms are structurally identical, and lessons learned from studying a partially ‘staged’ teaching and learning structure in one classroom may still yield useful insights about balancing degrees of freedom and constraint in other classrooms.

3.8.2 Identifying learning

A second validity concern were the limitations of asking pupils to identify and describe moments of their own learning. As previously discussed, learning is ‘difficult to pin down’ (Ewens and Cammack, 2019, p.34) and can be tacit and incidental Alexander, Shallert and Reynolds (2009). The hidden qualities of learning are also evident in the fact that when assessing pupils’ learning even teachers, at best, make inferences about what has been learned. Considering the challenges of validating that learning has occurred and the aforementioned limits on metacognitive reflection by children (Dunlosky and Metcalfe, 2009), there was a risk that the self-reported pupil MoL data would not in fact represent a record of genuine learning. This had the potential to be a considerable design weakness.

Mitigation against this risk was to ensure the self-reporting MoL process was as clear, user-friendly, and well-explained as possible to give pupils the best possible chance of understanding what was being asked of them and the best possible chance of fulfilling it accurately. It was accepted that there would be inaccuracies in the MoL data, including noticed and unnoticed errors. It was also accepted that because some learning is inaccessible to teachers and learners themselves, self-reported MoL data might only capture surface learning from which deep analysis of emergent self-organisation might not be possible. Considerable thought was given to alternative mechanisms for accessing insights about pupil learning, however from a methodological, ethical and purely practical point of view, I concluded that the very best hope for gleaning accurate and authentic data on instances of learning was a user-friendly and well-explained self-report procedure, complemented by corroboration from video footage and individual pupil interviews.

3.8.3 Explanations of learning

Related to concerns about the accuracy of MoL data was the concern about limitations on pupils' capacity to explain the origins of their learning when interviewed. This was essentially a metacognitive issue. Having posted MoL notes on the learning wall, the degree to which pupils were subsequently able to reflect upon and elaborate about the MoL varied considerably, from basic repetition of what was written on the MoL note, to more detailed explanations of the circumstances and other influences on the learning. The validity weakness here was that pupils might render irrelevant, inaccurate or indeterminate reflections on their learning and that the data would not accurately contain what it claimed to. The semi-structured nature of the interviews militated against this to some degree, making it possible to probe pupils to a greater or lesser extent as required, to elicit as detailed reflections as possible, though the level of insight across the sample remained variable.

The principal reliability concern was the lack of repeatability. Whilst the procedural elements of each data collection method were repeatable (MoL, video episodes, pupil interviews, journal and field notes), decisions about what to film, when to film it and for how long were largely in-situ judgements based on context, instinct and a real-time interaction with the data as it was collected. This situated approach would be impossible for another researcher to replicate precisely which raises questions about the verifiability of any claims made from analysis of the data. This subjectivity is discussed further in Chapter Eight.

4.0 Ethics

The study was framed ethically by the British Educational Research Association's (BERA, 2018) guidance for educational researchers. Pertinent responsibilities towards participants included i) maximum possible transparency about the form, processes and purposes of the research, ii) eliciting voluntary informed consent and assent, as well as knowledge of the right to withdraw, iii) ensuring no harm arising from participation and iv) respecting privacy, confidentiality and anonymity. How these ethical principles were upheld is described in the first sections of this chapter. Following this is a discussion of ethical issues relating to relational power dynamics between researcher and participants.

4.1 Transparency, voluntary informed consent and right to withdraw

BERA (2018, p.16) guidelines state that researchers should 'aim to be open and honest with participants […] avoiding non-disclosure […]'. Transparency about the form the research will take, the procedures in which participants will engage and their purposes is a key element enabling genuine informed consent. For this study, full and transparent disclosure about all aspects of the research was necessary at three levels of school hierarchy (Feldman, Bell and Berger, 2003), headteacher, class teacher and pupils. Informed consent was also required from parents and guardians, outside the school. Ensuring that participation at institutional, pupil and parental levels was as volitional as possible was important, as consent at each level influenced consent at the other levels. Therefore, stakeholders were approached and informed one by one, beginning with the head teacher as the institutional gatekeeper (Heath *et al.*, 2007; Morrow and Richards, 1996) and essential mediator (Andoh-Arthur, 2019).

The head teacher and I met approximately four months before the research week and discussed the research aims. I explained the theoretical and pedagogical background to the study, including why the research was worthwhile and we discussed possible outcomes, including those that may be of interest to the school. The proposal was met enthusiastically, and the head teacher explained that openness to research and respect for research evidence was a core institutional value. The school had existing ties with the university via previous research projects and the head teacher, keen to facilitate the present study, gave verbal informed, voluntary institutional consent, based on our thorough and transparent discussion.

Descriptions of challenges obtaining institutional access is prevalent in educational research literature (Wanat, 2008; Troman, 1996;), though I found I was largely pushing at an open door in this case. The head teacher also provisionally nominated the Year 4 class teacher and class to participate, stating that she believed the teacher would be interested and would benefit professionally from the experience. She felt that the research project would be ideal for the Year 4 pupils. The head teacher and I met periodically during the weeks leading up to the project commencement and during the project week itself to reconfirm plans and details. Her interest in how the project was unfolding and readiness to facilitate it were apparent and I took these as signs of assumed ongoing consent (Homan, 2001), what Heath *et al.,* (2007) refer to as 'process consent'. Gaining access to research fields is thought to depend considerably on relationship building (Feldman, Bell and Berger, 2003) and communication (Widding, 2012). Communicating, building professional rapport and mutual respect with the head teacher proved not to be challenging.

The next level of consent was from the class teacher, who, having discussed the proposal with the head teacher, contacted me to express his interest. We discussed the research, its aims and likely processes and he expressed his enthusiasm to participate. The literature abounds with discussion about the efficacy of children's consent, particularly in school contexts where teachers and school leaders may already have consented to institutional participation (Kirby, 2020; Cocks, 2006; Denscombe and Aubrook, 1992) and where pupil conformity is expected (Biesta, 2009). However, discussion of similar pressures on teacher consent, where head teachers have already given institutional consent, is difficult to locate. I explained that it was important the teacher felt he could decline to participate, however he confirmed that this had been made clear to him by the head teacher. Having established that he felt permitted to make an uncoerced choice about participation, and with knowledge of his right to withdraw at any time, he confirmed that he was keen to participate and gave his voluntary, informed consent on the basis of our thorough and transparent discussion (see Appendix F). The teacher and I met a further three times before the beginning of the research week to plan activities and establish how our researcher and class teacher roles would differ and overlap during the week. These occasions, along with our regular email communication prior to the research week, and daily discussions during it, enabled me to 'remain sensitive and open to the possibility that participants may wish, for any reason and at any time, to withdraw consent' (BERA, 2018, p. 9). The teacher's positivity towards the study gave me confidence about his ongoing consent.

Consent was also sought from the children themselves and from their parents or guardians. Parental/guardian consent was obtained via a direct letter from me which was distributed by the school office. In the letter I introduced myself, briefly described the aims and processes of the research, including details about research week activities and data gathering methods, including the protocols for capture and use of video recordings. Descriptions of how data would be captured, transferred and stored were given and the right to withdraw their children from the study was clearly articulated. I invited parents to contact me directly if they had further questions or concerns, though none took up this offer. The letter also gave the proposed dates of the research week and confirmed institutional approval. Fletcher and

Hunter (2003) discuss the importance of constructing consent letters which are clear and easy to read. For this reason, I chose not to attempt to describe the theoretical underpinnings of the research but to explain my intentions to 'document moments in which learning emerges in an attempt to gain a better understanding of exactly how, when and why learning occurs.' Signed parental consent letters (see Appendix G) letters were returned by all parents/guardians giving active consent (Esbensen *et al.,* 2008; Fletcher and Hunter, 2003) before the research week commenced. Several circumstances facilitated the positive response rate. Firstly, parents were made aware that the school had already agreed to participation in principle. This gave credibility to the request for consent since they knew that the research had the 'support of school personnel early in the process' (Fletcher and Hunter, 2003, p.217). Secondly, this cohort of children had participated in previous research projects with the university, so parents had had previous positive experiences with external researchers. Thirdly, the video capture would be undertaken using the school's IRIS system equipment and software which was routinely used for monitoring of teacher professional development. This gave parents confidence that the sensitive issue of videoing pupils and storing the data would be approached using a system for which they had already given their consent. Finally, I introduced myself as a university teacher educator and former primary school teacher. This was intended to give confidence to parents that whilst I was an outsider in terms of this school, I was an insider in terms of primary class teaching.

To begin the process of obtaining assent from the pupils, from whom most data would be elicited, I began by presenting and discussing the project with them face to face, approximately four weeks prior to the research week. The teacher requested that the subject matter of the project week remain secret initially so that he could build some anticipation among the pupils, therefore this initial conversation with the class focussed on general points about the research elements of the week, essentially what I would be doing and what I would request them to do. Pupils had opportunity to ask questions and clarify their understanding of the plan. I visited the class on two further occasions before the research week began and, on each occasion, pupils had further opportunities to ask questions and their right to withdraw at any time was reiterated. Pupil assent forms (Appendix H) were signed by all 30 pupils during my third and final visit. Following this, the teacher ran a series of data gathering pilots to trial the MoL procedures and iron out any logistical or procedural issues with the self-reporting system. This also exposed pupils to one of the research procedures, enabled them to ask questions, for example about the distinctions between knowledge, realisation and skills, and make procedural suggestions such as storing blank post-it notes on every table.

BERA guidance (2018) designates age as one factor which may prohibit a participant from giving voluntary informed consent and stresses that when researching with children 'researchers should fully explore ways in which they can be supported to participate with assent' (p.15) instead. The process of obtaining informed assent from children is recognised to be complex. Cocks (2006, p.257) describes assent as a relational approach in which researchers do not assume children's agreement to participate occurs only at the beginning of research but remain vigilant to a range of cues to continued agreement (or otherwise) throughout the research. Kirby (2020) points out that children may lack interest in descriptions of research plans and processes and may not comprehend what they are being asked to participate in. Key challenges therefore include ensuring that information about the research is continually communicated age appropriately and building the necessary rapport to notice signs of ongoing assent, or otherwise. The multiple opportunities pupils had to ask questions and discuss and trial procedures mitigated against these to some extent. Holding back the theme of the research week (rocket building) until after the pupils had given their informed assent meant I could be confident that they were assenting to the research and not to the rocket building. By far the biggest concern with obtaining assent from pupils, and the most significant preoccupation in the literature, is the issue of whether assent from legal minors, particularly in institutional settings, can be viewed as reliable. To help researchers problematise this question, Gallagher et al., (2010) suggest asking whether the act of assenting is part of pupils' everyday lives? In school, pupils are immersed in a culture of conformity (Biesta, 2009) which according to David, Edwards and Alldred (2001) make them problematic sites for consent, since even assent can easily 'shade into coercion' (p.351). This was a particular danger in this research because, although the pupils were unaware of the theme of the project when they first assented, they were aware that it would be a supported and sanctioned school activity, for which they would already be a 'captive audience' (Denscombe and Aubrook, 1992, p. 129). Prior school consent was implied by the fact that the research was presented to pupils by their teacher and me together, adding, on one hand, to its credibility, whilst simultaneously diminishing the likelihood that pupils would decline to participate. It is likely that had any pupils wished to opt out, they may not have felt confident to do so. However, whilst schools are not generally orientated to encourage questioning behaviours from pupils, there were factors which gave me confidence that my assessment of pupils' ongoing assent in this case was likely to be correct.

Firstly, the case study school had 'Rights Respecting School' status, a United Nations International Children's Emergency Fund (UNICEF) UK standard awarded to schools which demonstrate the values of the United Nations Convention on the Rights of the Child (UNCRC). These include an emphasis on pupils knowing their rights. Preliminary visits to the class demonstrated that 'rights' were referred to regularly, both by the teacher and the pupils. Secondly, the extended period of consultation between my first and third preliminary visits, supplemented by the class teacher between my visits, gave pupils many opportunities to raise concerns. Thirdly, as previously described, the pupils were able to question and discuss the research plans and purposes, as well as trial and help shape the data gathering procedures. This resulted in a degree of co-construction for the ongoing assent (Wittington (2019). Finally, and perhaps most significantly, the pupils implicitly (and correctly) judged that the tacit endorsement of their class teacher and head teacher could be trusted. In my assessment as an experienced teacher, pupils were relaxed and content to mirror the trust of their responsible adults when considering participation in the research project. Trust in adults is often viewed as part of the problem in discussions about children's consent/assent, due to the asymmetry in power between adults and children (Kirby, 2020; Holland *et al*., 2010; Lundy, 2007), and that asymmetry usually viewed as needing rebalancing (Tisdall, 2015; Percy-Smith and Thomas, 2010). However, power asymmetry serves vital purposes in schools, not only gatekeeping research activities such as this, but in the everyday functioning of the school. Trust placed in the judgement of responsible adults in positions of power protects pupils from potential harm far more than it places them in potential harm. Power itself is not the problem, but corrupt wielding of power which, fortunately, is exceptionally rare in UK schools. To the extent to which their assent was influenced by trust in their teacher and head teacher, that trust proved a reliable point of reference for pupils' decisions to participate.

As with the class teacher, pupil assent was viewed as a process, not an event. Dalli and Te One (2012, p.6) point out that research with children requires a 'continually responsive stance' in which researchers are sensitive to children's rights, including their ongoing agreement to participation. Flewitt (2005) argues that children's consent is always provisional and should be grounded in researcher-child relationships, characterised by sensitivity and reciprocal trust. My relationship building with the pupils began weeks before the research activity commenced during my three preliminary visits, each of which lasted between approximately three hours. Time spent with the pupils discussing the research, but also supporting them with their class work and talking socially to them helped established a useful trusting, relational foundation. This, coupled with my years of experience teaching this age group made judging the pupils' ongoing assent relatively easy in the familiar situated context (Simons and Usher, 2000) of the classroom. During the research week, I was able to constantly take the temperature of the pupils' agreement to continued participation through my observations of, and interactions with them. I was also able to gauge the pupils' ongoing willingness using my relationship with the class teacher as a pivot (Flewitt, 2005).

4.2 Video data collection and usage: privacy and anonymity

BERA (2018, p.22) recommend that when data collection includes video or other multimodal forms researchers may have to 'negotiate an ethical course of action' in relation to anonymity. Video material may also be vulnerable to misuse, so steps should be taken to maintain its security during collection, storage and analysis phases. Derry *et al.,* (2010) point out that it is the inherently non-anonymous nature of video captured data which makes it seem especially risky. Shuck and Kearney (2006) note that researcher sensitivity is required when undertaking video data capture with children, discussing issues of ownership and identification of individuals. However, they also urge researchers not to 'overreact' (p.453) and ignore the potential of video to elicit rich data and amplify young people's voices. Audio and video footage was captured using the school's IRIS hardware and software and files were automatically uploaded to the secure IRIS cloud storage where they remained until after the research week when they were securely downloaded to my encrypted and password protected One Drive folder. Video files of individual pupil interviews were shared with a university registered transcriber via the One Drive folder and were subsequently secure deleted by the transcriber using encryption software. All other video and audio data (whole class and small group footage) will be held securely on the One Drive for exactly twelve months after successful completion of the doctorate, after which they will be securely deleted. Video data were used for the purposes of analysis, using transcription (interviews) and sociographic representation. Apart from a small number of still images to aid the reader, video data are not presented visually in this thesis. Therefore, it was not necessary to seek consent for publication of video footage (Haggarty, 2020) from participants. For the purposes of analysis, pupils were given a numerical identification code meaning that during the analysis phase even I was unaware of their identities. Maintaining privacy and anonymity of participants therefore, only required measures during storage, transfer and transcription phases. From the day of its capture to its deletion, access to the video and audio data will have been limited to the class teacher (though data were deleted from his IRIS account after successful transfer to the One Drive), myself and the transcriber. In addition, steps were taken to ensure that data presentation, analysis and discussion did not compromise the identities of any participants.

Two additional issues are pertinent to the ethical capture and use of video data with children. Firstly, the nature of the activities being videoed and secondly, the possibility of capturing incidents of concern such as bullying or inadvertent disclosures of safeguarding issues. BERA (2018) highlight the importance of ensuring that participants are put at ease during research activities and that researchers avoid making excessive demands. Based on my experience, pupil activities during the research were wholly typical of a British primary school summer term enrichment week. Whilst the activities were more hands-on, the timetable more flexible and pupil autonomy levels generally higher than usual for the case study class, pupils were not required to make any notable adjustments in their approaches to learning. The activities (designing and making model rockets), whilst novel compared to their usual weekly schedule, would not have surprised or disorientated them. In this sense the video footage captured the pupils in their natural setting engaged in typical classroom activities, they were not required to 'perform' for the camera. The activities in which they engaged, whilst designed specifically for the research week, were age appropriate and worthwhile in that they met a range of Year 4 curricular learning objectives. In this sense the research had no detrimental effect on curriculum coverage, an aspect which influenced the head teacher's initial 'gatekeeper' consent. The naturalistic nature of the activities which pupils were filmed undertaking was both an important ethical, but also methodological consideration. As described in Chapter Four, whilst tweaks were made to aspects of content and pedagogy during the research week, maintaining a naturalistic and broadly 'business as usual' approach to the classroom was important.

BERA (2018) states that in the event a participant reports behaviours likely to cause harm to participants or others, researchers may be obliged to disclose confidential information to appropriate persons. The potential for inappropriate behaviours, or information about them to be captured in this study was heightened by the fact that much of the video footage captured pupils working independently, without the immediate presence of the teacher or researcher. In this study no such information was shared, consciously or otherwise, by pupils. However, I was not able to confirm this until analysing footage several months after the data was initially captured. This meant I had to be mindful of the possibility that acts of unkindness, exclusion, bullying, abuse or information relating to such things might be captured on video during the research week, and have a plan for how to respond retrospectively should this occur. Furey and Kay (2010) suggest that researchers must understand legal and procedural frameworks relating to child safeguarding, stating that researchers often feel inadequately equipped to make judgements about information they learn from participants. My experiences as a teacher and subsequently as a teacher educator equipped me with a sound working knowledge of relevant legal frameworks and understanding of school procedures relating to safeguarding. Having also become informed about local safeguarding procedures at the school, the head teacher, class teacher and I pre-agreed parameters for the disclosure of sensitive or safeguarding-related information arising from video captured footage.

4.3 Power asymmetries: researcher and class teacher.

My relationship to the teacher was multi-faceted and influenced various aspects of the research week, including the prevailing pedagogies and the data gathered. This section discusses the different positions the teacher and I held in relation to one another, the openness with which we attempted to approach them and the consequences for the research. It begins with an overview of the researcher-teacher dynamics, after which the consequences for the research are discussed with reference to relevant literature. Different positionalities between the teacher and me established an initial asymmetrical tone for researcher-teacher relations which we would then navigate throughout the research project. Although no data came directly from the teacher, his role and the researcher-teacher relationship was pivotal to the study. These positionalities were largely a consequence of asymmetries in professional experience and status. For the purpose of describing and analysing how these dynamics influenced the research, the following discussion of power dynamics is presented under these themes: i) consequences of professional status asymmetries for the research study and ii) professional asymmetries and the possibility of researcher-teacher equality. Following Vincent and Warren (2001) I use the term 'asymmetries' from this point because it alludes more usefully to the complexities and nuances of the researcher-teacher relationship and is less ideologically loaded than the term 'power'. I did not presuppose status asymmetries between myself and the teacher (Mitchell, 2010), however they were apparent from the outset.

4.3.1 Consequences of professional status asymmetries

Table 4.1 Shows an overview of the different professional positions the teacher and I held. The rows are used to indicate positions which correlate asymmetrically. Other status positions and factors followed from these (for example, I have taught in several schools whereas the teacher had only taught in one), however those in Table 4.1 represent the headline positions. Other wider contextual factors also influenced the researcher-teacher relationship, for example age (I am twice the teacher's age), however within the scope of this discussion only our respective professional positions are analysed. The arrows indicate higher or lower status.

Table 4.1 indicates that of the five professional points of reference between the teacher and me, I held higher status in four of them. I had previously been a primary class teacher for eleven years, compared to his ten months, I was a teacher of teachers, and he was a teacher, meaning he was aware that my day job involved training novice teachers. Moreover, I trained novices teachers at the institution where he undertook his training, and although I was not a regular contributor to his Post Graduate Certificate in Education (PGCE) programme and did not consider myself to be one of 'his lecturers', he recalled I had lectured his cohort on one occasion. Points one, two and three were discussed openly from the outset, particularly point three. This professional point of reference in particular shaped the asymmetries between us towards a student-lecturer dynamic, which required rebalancing periodically throughout the process. Point four was never openly discussed, but augmented asymmetries arising from point three in that the deficit of professional experience between us included that of researching as well as teaching. Reference to point five went some way towards rebalancing asymmetries caused by points one to four and also became a fulcrum around which I took steps to rebalance the relationship.

	Researcher	**Teacher**
1.	Experienced primary class teacher	Novice primary class teacher
2.	Experienced teacher of teachers	Teacher
3.	Teacher of teachers at my university	Previous student at my university
4.	Qualified to masters degree level, undertaking doctorate	Qualified to degree level, with PGCE
5.	Visitor in school / class (outsider)	Teacher in school / class (insider)

Table 4.1 Researcher-Teacher professional positions and consequent status.

The combined effects of points one to four in Table 4.1 were that from our first meeting the teacher assumed a subordinate position and followed my lead. This was undesirable for several reasons. Firstly, during the research week I intended to be as discreet and inconspicuous a presence in the classroom as possible. This meant the teacher would be the leader and facilitator of the learning activities and I would assume the role of researcher, subordinate to him in all matters pertaining to pedagogy, organisation, scheduling, content and data gathering. It was apparent from the outset that these asymmetries would need to be rebalanced. Various researchers have explored the question of how more equal partnerships can be established between researchers and the researched. Oakley (1981) suggested that researchers revealing information about themselves, as well as seeking information about participants through data gathering, was a useful strategy since it creates a mutual vulnerability. Munro (1998) advocates collaboration with participants as a strategy for removing hierarchies from researcher-researched relationships. Acker, Barry and Esseweld (1983) suggested researchers encourage participants to set the agenda for interviews, reveal information about their own lives and share written outcomes of research with participants.

There is, however, some consensus in the literature that attempts to equalise relationships between researchers and participants, whilst admirable, are limited in their effectiveness. Munro (1998) for example, reported that in collaborative research projects, participants are often not interested in having the status as collaborators, despite researchers' best efforts to reposition them. Johnson (2000) found in research into unemployment, with unemployed participants, that researcher-researched asymmetries were ultimately unalterable. Similarly, Smythe and Murray (2000) argue that whatever steps researchers take to equilibrate hierarchies, asymmetries are often methodological facts, and Scott and Usher (1999) posit that regardless of researcher attempts to democratise research relationships, researchers ultimately have control over studies because they analyse the data and author research reports. Whilst I took steps to lessen researcher-teacher asymmetries, like Smythe and Murray (2000) I accepted that absolute symmetry would not be achievable, in this case because the realities of our relative professional positions. This meant that mitigation was the best course of action and optimal outcome under the circumstances.

4.3.2 Professional asymmetries and the possibility of researcher-teacher equality

Table 4.2 shows the steps taken to mitigate against the effects of the asymmetries articulated in Table 4.1. These measures were ongoing throughout the preliminary and planning phase and into the research week itself and were intended to position me from the teacher's point of view as i) a learner, ii) in need of his expertise, iii) an education colleague, not a lecturer/mentor, as well as managing any expectation that I was evaluating or judging him or his teaching.

	Researcher	Teacher	Mitigation
1.	Experienced primary class teacher ↑	Novice primary class teacher ↓	Positioned myself as still learning. Emphasised teacher's knowledge of the class. Adopted subordinate position in content & pedagogical planning.
2.	Experienced teacher of teachers ↑	teacher ↓	Positioned myself as still learning. Emphasised that would learn from the teacher. Not observing, evaluating or judging teacher. The primary object of study was learning, not teaching.
3.	Teacher of teachers at my university ↑	Previous Student at my university ↓	Discussed openly. Explained I viewed teacher as an equal. What he lacked in relative experience, I lacked in knowledge of the class What he lacked in relative experience, I lacked in recent experience.
4.	Qualified to masters degree level, undertaking doctorate ↑	Qualified to degree level, with PGCE ↓	Deliberately no direct discussion of this.

5.	Visitor in school / class (outsider)	Teacher in school / class (insider)	Emphasised this reference point regularly. I needed his expertise to create optimal conditions for the research. Emphasised he must take ownership of the project content and teaching.

Table 4.2 Asymmetries and mitigation measures.

These measures were partially successful in recalibrating the researcher-teacher relationship towards greater status symmetry. Through regular communication and reiteration of mitigating factors listed in table 4.2, the teacher and I established a useful working relationship in which he took the lead in matters relating to teaching and learning and I attended to research processes. However, this took time to evolve. One of the more significant methodological challenges which intersected with the asymmetries in Tables 4.1 was the pedagogical aspect of the research. To study learning as an emergent phenomenon, I required the pupils to have sufficient autonomy to allow for bottom-up innovation and system adaptation, but to be sufficiently constrained to avoid all out chaos. To occasion emergence certain organisational and pedagogical parameters would be necessary. For example, pupils should operate in whole class and small group contexts and some fluidity in movement between these should be encouraged, pupils should be involved in planning the project during the research week, pupils should have autonomy to utilise different spaces in the classroom and make decisions about their working practices. In preliminary discussions we considered the implications of these parameters, including the consequences for the research if pupils were too tightly constrained. At this stage the teacher was quite relaxed about facilitating this, however it became apparent on day one of the research week that these parameters would prove more challenging for pupils and less comfortable for the teacher than either of us anticipated. At lunch time the teacher and I discussed this, and I reiterated that this was his class, in his school and he must teach the project for the research week in a manner with which he was comfortable. I would adapt my research procedures to accommodate his chosen approach. This proved to be a pivotal moment in rebalancing our relationship. During the afternoon of day one and throughout the rest of the week the teacher shifted pedagogically closer towards his comfort zone, applying more supervisory structure to pupil activity, intervening more often, breaking up periods of independent group work with more frequent plenaries and being more insistent that every group follow more centralised procedures.

This presented a dilemma for me as a researcher, in that I had to choose between methodological and ethical integrity; whether to make an ethical compromise by insisting that the teacher continue with an approach with which he was clearly uncomfortable or make a methodological compromise by accepting that the pupils would have less autonomy than I hoped. Prioritising ethics over method was a compromise and did impact on data, however it also reinforced my commitment to subordinate myself as a visitor in the classroom, embodying in practice what had been discussed theoretically, that the teacher should take ownership of the content and teaching of the research week. After this hinge moment researcher-teacher status symmetry was tangibly enhanced.

4.4 Summary discussion

Post-positivist approaches to social research tend to presuppose a commitment to reduce status asymmetries between researchers and participants. Research including qualitative elements is often conceived as a co-constructed process, in which ‘the division between researcher and subject is blurred’ (Gergen and Gergen, 2000, p. 1035). This study was undoubtedly a collaboration, since I relied heavily on the teacher to lead the learning activities, adhering as closely as he felt able to the parameters I set. Equally, the teacher relied on me for constant feedback about how successfully he was balancing pupil autonomy and constraint. In this case minimising ‘distance and separateness’ (Karnieli-Miller, Strier and Pessach, 2009, p.279) of the researcher-teacher relationship came at a methodological cost, though ultimately one worth paying. However, Karnieli-Miller, Strier and Pessach (2009) point out that there is an apparent tension between the aspiration to equilibrate relationships in research and the primary commitment of researchers to make contributions to knowledge. In this case, my in-the-moment, reflexive judgement (Reid *et al*., 2018) was that the methodological compromise, whilst not insignificant, did not negate the possibility of generating useful data. It did, however, positively influence the teacher’s ownership of the project. This general shift from researcher ownership towards more shared ownership of the processes followed Karnieli-Miller, Strier and Pessach’s (2009) expected developmental trajectory which predicts that hierarchies will flatten-out as research projects move from sample recruitment and planning phases into data collection. In this sense the relational dynamics were just that, dynamic, and not inert.

Iterative judgements concerning the shifting relational dynamics between the teacher and me required a reflexive mindset. May and Perry (2014, p.111) stress the importance of reflexivity, describing it as a ‘characteristic of good research practice’. Through a recursive process of constant relational monitoring and checking-in with the teacher throughout the research week, we were able to negotiate pedagogical and process approaches concerning the rocket project which in turn enabled me to make necessary in-situ adjustments to the data gathering procedures. Brookes, Riele and Maguire (2014) discuss ways in which ethical considerations can impinge on methodological choices, which include decisions about research paradigm and research instruments. In rejecting the notion that methodology and ethics are separate and potentially conflicting concerns, they posit that effective research technique and ethical practice are ‘closely entwined’ (p.60). Relationships between methodological and ethical considerations were a significant and continuous feature of the research, particularly with respect to researcher-teacher asymmetries.

5.0 Data Analysis

This chapter presents the instruments, processes and steps employed in the analysis of data, from initial organisation of the different streams through to immersion, integration and representation. Terms and concepts relevant to the analysis are explained, limitations and mitigations described, and researcher decisions justified. The chapter also includes a reminder of the conceptual framing which formed the basis of the analysis. The analysed data follows in Chapter Six.

5.1 Data analysis steps

5.1.1 Initial organisation of data

Interview data were transcribed and initially organised by type, with video footage, interview transcripts and researcher field notes filed and stored separately. Next level organisation involved categorising video footage according to the models of whole class centralised, whole class decentralised and whole class distributed (see section 6.1.1). Moment of Learning (MoL) data were read and anomalous or unusable MoLs removed. Unusable MoLs included any that were blank, had missing information such as day or pupil name, or on which the handwriting was illegible. In instances where a pupil had written a clear and legible MoL but neglected to indicate the learning type, or misattributed the learning type, this was corrected and included in the usable data set. MoLs were organised by pupil, the post-it notes stored securely and their contents collated and tabulated according to pupil, day and learning type. Following this, all video data were viewed in-full, in order to eliminate episodes unusable due to inaudibility or technical issues. Every pupil was allocated a numerical code from one to thirty and these codes were applied to all MoL and interview data. All video files were named including day (of the research week), time and the number codes of the depicted pupils for ease of identification and triangulation across data sets. Pupil number codes were double checked against the class list and across all data sets to ensure accuracy.

After these procedures, the following data were deemed suitable for analysis:

- **14 individual pupil interview transcripts**.
- **10 decentralised group work video episodes** (totalling 2 hours 16 minutes and 28 seconds), 5 of which (totalling 1 hour 8 minutes and 31 seconds) were analysed and form the basis of the results. (For transparency, the remaining 5 episodes are summarised in Appendix I with explanations for their exclusion).
- **6 centralised whole class video episodes** (totalling 1 hour 4 minutes and 31 seconds)
- **2 distributed whole class video episodes** (totalling 19 minutes and 50 seconds)
- **152 individual MoL post-it notes**.
- **Tabulated MoL data** disaggregated by pupil, day and learning type.
- **Researcher field notes.**

5.1.2 Points of reference for analysis and interrogative framework

Although the focus of this study was learning in decentralised small group systems, small groups are nested within classrooms and therefore conceptualising the classroom system through a CAS lens was essential. It is not possible to elicit authentic insights about group learning separately from classroom learning. Selected CAS criteria detailed in table 3.1 of Chapter Three (and presented again below in Table 5.1) were therefore used to create a working definition of a complex adaptive classroom system (CACS):

A system containing multiple autonomous, interacting pupils, whose inter-relationships create networked, emergent, non-linear behaviours from which self-organised change (learning) emerges.

CAS criteria	Definition
Self-organisation *observable phenomenon *interactive dynamics *pupil subcultures *spread of knowledge *imitative behaviours	organised patterns of synergistic behaviours which aggregate across the system.
Emergence *Bottom-up behaviours *Bifurcations *Perturbations/injection of novelty *Unpredictability *Evidence of non-additive learning *Impulsive/instinctive behaviours *Local decision-making *Pupil autonomy *Well-networked interactions	phenomenon arising from the bottom-up within the system. Changes initiated locally rather than centrally.
Non-linearity *Causation networked *information moves back and forth between pupils	information moves between agents via feedback loops and signals, therefore causality is not linear but networked and recursive

*Pupils send and receive signals	
Transcend their components *Produce learning beyond knowledge/capabilities of each individual.	exhibit properties not manifest in individual agents; systems that learn; learning is more than the sum of the system parts

Table 5.1 CAS criteria selected to frame analysis.

The criteria in Table 5.1 and the CACS definition above were used to derive complexity-informed questions with which to interrogate the data (interrogative questions) seeking to confirm and/or refute my working hypothesis that learning can emerge. Though these characteristics were not coded for the purposes of analysis, the analysis nevertheless was framed deductively around them and the subsequent interrogative questions they gave rise to. The range of interrogative questions included:

- What learning is evident, including indicators of potential or future learning?
- What factors may have contributed to this?
- What system dynamics are influential?
    - Degree centrality
    - Influential ('salient') pupils
    - Environment / climate
- Is there evidence of:
    - self-organisation?
    - Non-linearity?
    - Emergence?
    - Transcendent learning?
- What conditions prompt these ('antecedents to learning')?

To determine whether and to what extent learning can be said to have emerged, the following definition of emergent learning was created, drawing on criteria in Table 5.1:

Learning, potential, tangible or elaborated, which materialises through autonomous interaction between pupils, resources and environment, rather than directly from top-down teacher control.

5.1.3 Data immersion and presentation

Next followed a process of video data immersion. Each video episode was watched in-full twice and initial notes made in response to the key interrogative questions and prompts about possible triangulation with other data sets noted. A combination of adopting a mindset open to noticing small details and non-linear thinking revealed general and specific clues about the content of the video data. With a thorough overview of the video data content, the next step was to select and develop strategies for depicting salient characteristics of the system dynamics evident in each episode and evidence emergent learning.

Social Network Analysis (SNA) - Sociographs

The next level of video data analysis was also immersive and involved applying a relational social network analysis (SNA) to each of the 10 decentralised group work video episodes, depicting matrices for direction and weight of interactions (Figure 5.1). SNA has been used by several classroom researchers to map pupil connectivity. Johnson (2016) illustrates how different types of networked interaction between teachers and pupils and pupils and pupils (instructional, emotionally supportive, behaviour management) can critically influence classroom climate and pupils' readiness and willingness to engage with learning activities. Other studies (Bokhove, 2018; Liu, Chen and Shu-Ju, 2017; Cooc and Kim, 2016; Grunspan, Wiggins and Goodreau, 2014; Mameli, Mazzoni and Molinari, 2015) have also analysed peer to peer connectivity and interaction using graph theory and SNA to better understand distributed peer effects on learning within classrooms. SNA explores social relationships through the lens of network theory by analysing data on the connectivity of individuals. SNA is based on assumptions that interconnectivity within a classroom shapes pupils and teachers, that pupils and teachers shape the networks, that peers influence peers and that networks have lives of their own that produce emergence (Christakis and Fowler, 2009).

Sociographs were used to capture impressions of relative member influence on the group activities. In a sociograph, nodes (circles) represent individual pupils and edges (lines) with arrows indicate utterances from one node to another. Edge thickness indicates the quantity of interactions. Degree centrality refers to the extent to which a network is or is not centralised around certain nodes. A node’s in-degree (number incoming interactions) and out-degree (number of outgoing interactions) ratio indicates its influence within the system. Nodes receiving more interactions (in-degree) than they send out (out-degree) are considered particularly influential, nodes sending out more than they receive are considered less influential. The scale of nodal (member) influence within the group is depicted by their node’s relative size in the sociograph. In the example below, pupil 12 exerted most influence on group interaction with an in-degree/out-degree ratio of 38-30 (expressed in net-form as ‘in-degree +8) and therefore the largest physical node (circle).

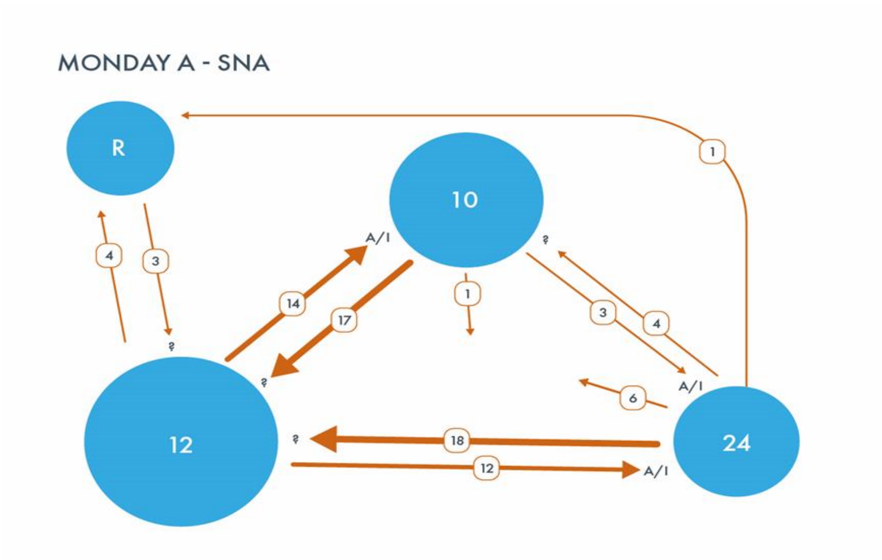


Figure 5.1 Example of sociography derived from scrutiny of a videoed group work episode. (Question marks indicate most interactions were questions. A/I indicate answers or instructions).

However, because not all utterances exerted equal influence on the group and not all group members were present for the full duration of each episode, three additional qualifying criteria were applied to judgements of relative influence: i) duration of presence in the episode, ii) significance of utterances and iii) degree of connectivity. Significance indicates whether and to what extent utterances influenced the course of events in each episode. Insignificant utterances had no noticeable effect on proceedings. Significant utterances influenced subsequent interactions, group decisions or actions, in either a disruptive or constructive way (see Appendix J for examples). If a member had a net positive in-degree but was only present for a small proportion of the episode their relative nodal size was adjusted downwards to reflect this (presence adjustment). Equally, the node of a member who had a net negative in-degree but whose utterances were particularly influential on the group would be augmented (significance adjustment). Adjustments to relative nodal size were also made to reflect how many other group members each node connected with. To be connected with another member, a node required at least one in and one out interaction with that member. Possible connectivity included outsiders who interacted with group members, including the teacher and the researcher. If a node was present throughout the episode with an apparently influential in-degree but only interacted with one other node, their overall relative influence would reflect this (connectivity adjustment). In some episodes overall influence was proportionate to net in-degree, however, where duration of presence, connectivity and/or significance of contributions altered influence, adjustments were made. Relative nodal size therefore represented a judgment about relative group influence based on net in-degree, length of presence, connectivity and uptake of contributions. Adjustments for length of presence, connectivity and uptake of contributions were not formulaic but impressionistic based on my judgements about pupils' relative influence on the small group system.

Each episode was viewed, and the direction and weight of every interactive utterance was mapped manually (pen on paper – Appendix K) and each node's in-degree and out-degree recorded. This data was then used to create sociographs to visually represent the interactive dynamics of each video episode. The process of observing/listening to pupil interactions and pausing the video to manually record them and creating sociographs, in addition to the initial double viewing of each video, facilitated a sound and detailed familiarity with every episode and made their interrogation easier and more productive. Videoed episodes were selected for sociograph analysis based on their having captured self-reported MoL, due to links with other video captured episodes and/or because they included sufficient density of interaction and/or evidence of learning.

Interaction type pie charts

Following the creation of sociographs, interactions in each episode were disaggregated by type and presented proportionally using pie charts. Scrutiny of the relevant literature on pupil group interactions led to selection of the following interaction types for analysis purposes:

- Procedural (concerning what to do) (Blatchford *et al*., 2006; Edwards and Mercer, 1987)
- Member roles (concerning who would/could/or should do what) (Baines *et al*., 2008)
- Substantive subject knowledge (questions, answers, suggestions) (Mercer and Wegerif, 2004)
- Explanations (about the substantive topic) (Barnes, 2010; Mercer, 2008; Mercer and Hodgkinson, 2008)
- Conflict (disagreement or dispute) (Baines *et al*., 2008; Blatchford *et al*., 2006)
- Miscellaneous (utterances spoken to self, off-task or inaudible) (Yonge and Stables, 1998; Beserra, Nussbaum and Oteo, 2017; Langer-Osuna, 2018)

For this analysis, interactions denotes all utterances from group members (or other actors who tangibly influence the group) where another individual, individuals or the group at large are deemed to be the intended audience. Therefore, all pupil or adult utterances which fit these criteria were labelled 'interactions', even where an utterance received no obvious reply. Pie charts were used to illustrate the proportion of interactions in each video episode which fell into each of the above categories. This was useful in the following ways. Firstly, for general scene setting and context. Secondly, when compared with the nodal influence data shown in the corresponding sociographs, it was easier to understand ways in which certain nodes (pupils) exerted (or failed to exert) themselves on the system. Thirdly, pie charts provided a useful context for identifying how different types of interactions contributed to learning evident in a given episode.

Critical Learning Incident (CLI) timeline graphs

Each episode was then viewed a final time and critical incidents of pupil learning identified. For the purposes of analysis, critical learning incidents were categorised as ‘potential’, referring to incidents where current or future learning could be implied or inferred, ‘tangible’, referring to incidents where learning was obvious and apparent and ‘elaborated’, referring to incidents where tangible learning was extended or developed, through explanation or reasoning for example. Critical learning incidents were presented in an adapted form of timeline graph (Figure 5.2) indicating which category of critical learning incident had occurred at approximately which point in the timeline of the episode. Critical learning incidents were described, contextualised and combined with other data sources to form chronological narratives of learning.

The combination of sociographs depicting group interactive dynamics and interaction type pie charts provided a) a multidimensional understanding of each video episode, b) complementary and comparative points of reference for analysis of each episode and c) useful representations through which to interrogate each episode. In addition, since producing each analytical representation demanded multiple viewings of each episode, a range of insights were elicited which were inaccessible from the initial viewing. Each of these representations were therefore valuable as products, but also as processes.

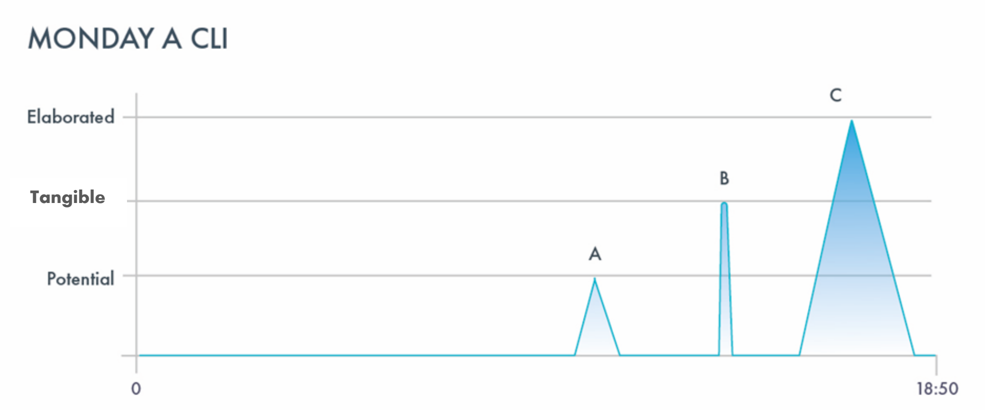


Figure 5.2 Example of critical learning incident timeline graph.

5.2 Triangulation with other data sets – building narratives of learning

Having produced immersive multidimensional representations of a video episode, the next stage was to follow lines of enquiry emerging from the critical learning incidents which led to other data sets, including other video episodes, MoL post-it notes, individual pupil interview transcripts and researcher field notes. Having separated and read MoLs from the relevant pupils for the week and begun to explore links between these and evidence of learning in the video episode, the range of other data sets were scrutinised. For instance, in a particular critical learning incident a pupil might have explained a hypothesis about how their rocket would perform when tested. At this stage other video episodes would be reviewed for evidence of that group's rocket test or further discussion of the hypothesis or test outcome. MoL data would be reviewed for all pupils in the group and scrutinised to ascertain whether the same pupil or others from the group had referred to this topic in their MoL contributions that day, or on subsequent days. Individual interview data for the pupil in question, or others in the group would be reviewed for relevant references. Relevant extracts from the researcher's field log were integrated to add context to the analysis. Each learning narrative represents a series of snapshots of learning which amount to a tiny fraction of interactions across the research week. Once all relevant sources of data relating to a given critical learning incident were identified they were linked chronologically, presented and analysed by means of posing the interrogative questions in order to develop insights about whether and how learning emerged, its antecedents and networked effects. The results were then presented as chronological narratives, starting with social network analysis of the video episode and branching out to incorporate related evidence from other data sources to present a narrative about the origins and influences on the learning.

In total, three chronological narratives of learning were analysed comprising five decentralised group work video episodes and drawing on a range of other videos, interviews and MoLs from the available data sources. Common and recurring characteristics across these three narratives were then identified and discussed.

5.3 Analytical integration typologies

As Poth (2012; 2018) has emphasised, ‘off the shelf’ typologies rarely suffice in complex research contexts. This proved to be the case. Decisions concerning integration of data sources began during the research week itself and just as data gathering strategies evolved in real-time in response to unfolding events (see Chapter 4), so plans for data integration also evolved. In fact, it would be more accurate to say that data sources and plans for data integration and analysis co-evolved during the research week, because in this complex research context it was the complementary integration of data sets, not the individual data sets themselves, which held the potential to unlock insights about emergent learning. This is because when researching a complex phenomenon in a complex and constantly evolving researching environment, no individual data or series of separate data sets tells a complete story. Only when integrated appropriately did the data sets bring the best out of one another. This corresponds with Poth’s (2018, p.74) assertion that mixed methods complexity-sensitive approaches ‘cannot be thought of as a set of steps to be followed’. Rather, adaptive mixed methods research practices are a mindset based on integrative thinking and ‘congruence of design’.

Whilst the pupil interviews and researcher field notes were purely qualitative data sources, both qualitative and quantitative data were elicited from the video footage. Conventional approaches to qualitative and quantitative data analysis are linear, however multiple viewings and re-viewings of the episodes of video footage represented a more iterative process of moving forward and backwards through the data to identify relevant points of reference for analysis.

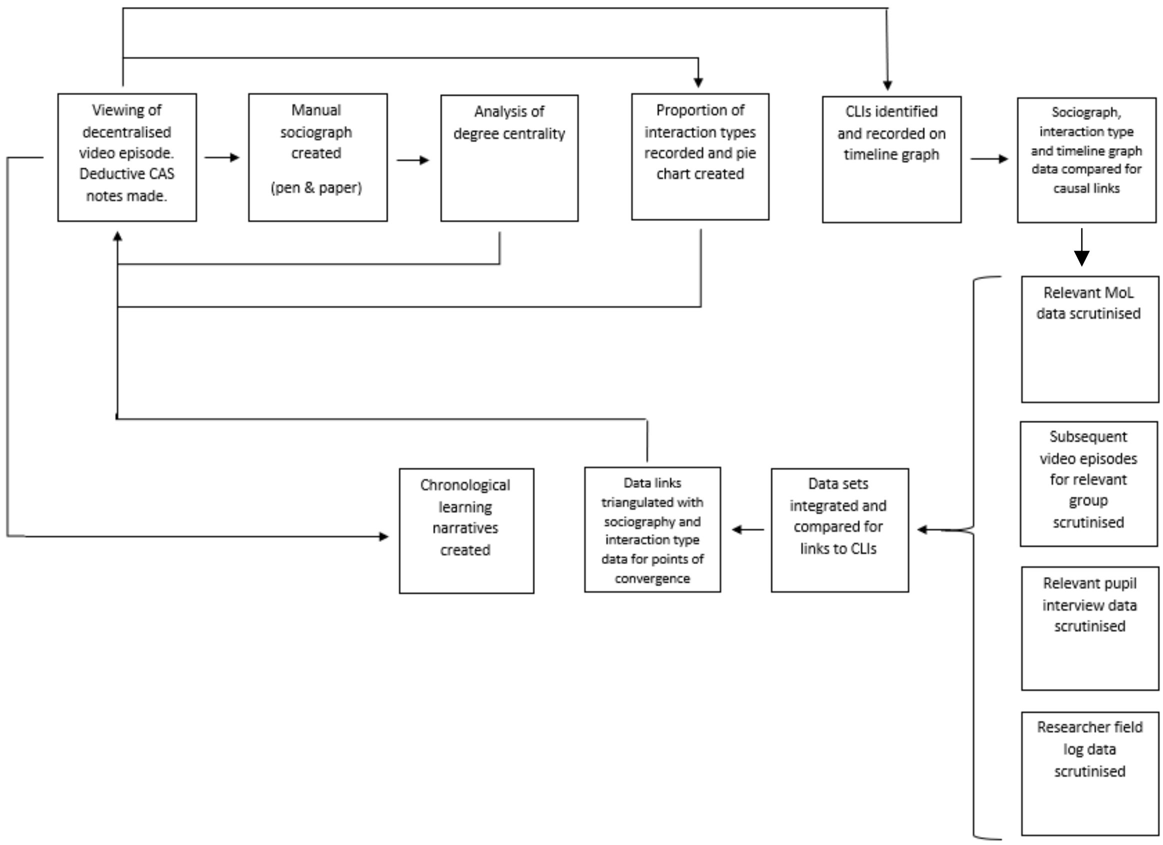


Figure 5.3 Iterative integrated process of data analysis.

The processes described in Section 5.2 above are illustrated in Figure 5.3, which shows how developing the learning narratives involved returning repeatedly to the video episodes to review, consider and triangulate. Episodes were scrutinised in detail in order to notice micro-level features of each interaction which might give clues as to the nature and emergent origins of the critical learning incidents. As noted in Chapter Three, valid questions have been raised by a range of authors (Poth, 2018; Bazeley, 2018; Creswell and Plano Clark, 2018; Greene, 2007 among others) about data integration and its effect on the quality of analysis (see Section 3.4.1). In this study, plans for integration were forming before the research began, and whilst final decisions about how the data sets would be integrated were not made until immersion in the data began, broad judgements about how video, MoL and interview data in particular would converge were forming before and during data collection.

Revealing inferred or otherwise tacit insights about learning required certain habits of mind. Firstly, it was necessary to adopt an open mind in order to notice small details and appreciate their potential significance. The intention to discover insights tacit within the normal course of everyday classroom activity demanded an attention to detail beyond that which a teacher might be able to apply to learning episodes. This meant reflecting on incidents which might ordinarily have been considered trivial. It was necessary to stop thinking like a teacher (as is my default after 11 years in the classroom and a further 12 years teaching about teaching) and think like a researcher. When viewing video episodes, reading and considering MoL data and reviewing interview transcripts, having noticed what any teacher would notice in the data, I then asked myself 'what else is implied here'? The CAS-like characteristics (Table 5.1) and interrogative questions provided a framework for this 'thinking differently'. One of the key differences (and something which did not come naturally initially) was thinking non-linearly about the data. Having noticed and speculated about the significance of seemingly insignificant incidents, I then set aside my linear habits of mind that sought immediate and proximal antecedents, in favour of networked thinking about the multiple factors which may have contributed to them and to which they might also contribute. This took practice and discipline.

5.4 Salient individuals

Analysis of group video data revealed that in each episode certain pupils exerted degrees of influence on the 'system' for different reasons. The locus of control in group work episodes coalesced around such pupils and they were designated as ‘salient’ for the purposes of analysis and discussion. Salience revealed itself primarily through social status, knowledge status or certain personality traits including conscientiousness and perseverance. Salience was a subjective attribution I made based on repeated viewings of each video episode, drawing on my experience as a teacher and what the data revealed. In some instances, salience was aligned with in/out-degree sociograph data, however on occasions pupils exerted influence on group activity without having been a significant hub through which interactions travelled. Salience was often related to, but was not tied to, individuals’ quantity of interactions. For example, a conscientious pupil might interact infrequently within an episode, but be responsible for keeping everyone focussed and on-task. This individual could be designated as salient in that episode. Another salient individual might have apparent high social status leading others to follow their every suggestion, exerting a different form of influence on the group dynamic and activity. Social status showed itself in a variety of ways. In some cases, high social status pupils dominated conversation, in other cases they said little. In some cases, they were disruptive and in others conscientious. The key feature of social status, compared to other forms of salience, was that a majority of group members followed their lead, listened to their utterances, permitted, tolerated or enabled their influence. Judgements about pupil social status were based on my perceptions of indicators (also used by Acquah *et al.*, 2014) including high peer acceptance, popularity and prominence in classroom social structures. Salience was not a fixed phenomenon, pupils who were salient in one episode may not have been in another, and vice versa.

5.5 Limitations of analysis processes

The messiness of social contexts (Uprichard and Dawny, 2019) means that all attempts to capture and understand them inevitably fall short. As such, there were limitations with the processes of analysis.

Firstly, even using analytical reference points and deriving specific questions with which to interrogate the data, judgements about its significance were subjective and therefore whilst the processes may have been replicable by another researcher, the interpretations, findings and conclusions which followed, would not. Another researcher analysing the same data, following the same processes would be likely to derive similar, but not identical interpretations. Emergent learning (particularly in non-elaborated forms) is in the eye of the beholder. Secondly, interpretations are limited to what is observable in the data and, as discussed in Chapters One and Three, there is much about learning which is unobservable. This means that interpretations of the data sets, however based on immersion and meaningful integration they were, failed to capture much that was occurring. On occasions when too much was tacit to make confident inferences, it was tempting to make interpretations drawing on my teaching experience to fill gaps in the data. Being honest, clear and strict about locating (and not crossing) the line between data and my experience of multiple similar classroom situations was crucial (this is discussed further in Chapter Nine). Though I did infer and speculate in my analysis, I was committed to maintaining the integrity of the work and only did so as far as was reasonable based on the data. Thirdly, only using five out of the ten group work videos and a limited selection of the MoL and interview data could be seen as cherry-picking. As explained in Section 5.1.3, video data were selected for inclusion based on content and data integration criteria. The five excluded episodes (Appendix K) contained partial or incomplete groups (e.g., more than half of group members exiting and not returning for long periods), very limited interaction or continual teacher presence which substantially limited pupil autonomy. Selected episodes stood the best chance of contributing to narratives about learning as emergence. As explained in Section 5.2, MoL and interview data were included where they crossed over with pupils, critical learning incidents and events captured in the video data. In this sense they were 'cherry-picked', not because they fitted my agenda as a researcher, but because they had potential to reveal otherwise tacit insights about learning. Morrison (2012) warns about ascribing causality to small amounts of included data whilst ignoring the possible implications of excluded data. In light of this, and whilst acknowledging the challenges of accessing insights about the emergence of learning, I have been thoroughly transparent in Chapters Seven to Nine about what can and cannot be derived from the included data. To avoid accusations of cherry-picking from within the included data, I have analysed and reported on it from multiple angles, integrating multiple approaches. Fourthly, as a tool for unpicking and representing group interaction, sociographs have benefits and limitations. Degree centrality is a one-dimensional representation showing that interactions occurred, but without quantifying their value. For example, a monosyllabic pupil could appear to have been contributed much because they interacted frequently, whilst actually contributing little because their utterances were limited in scope. This speaks to a valid criticism of social network analysis from Byrne (2014) who argues that it is useful to explore, but not to explain. To confirm that the sociograph data was not skewed by this, I analysed video episode 'Monday A' excluding any utterance under three words long from the data (see Appendix M). This significantly lowered the overall interaction count and did have the effect of excluding much of the 'miscellaneous' interaction data. However, it also excluded some potentially influential utterances, revealing that to affect the group dynamic an utterance does not have to be lengthy. Interestingly, this approach also did not alter the degree centrality of the sociograph. Based on this 'test-case' I followed planned procedure and included all interactions in the sociograph data, confident that while they only told a part of the story of the learning narratives, integration with the other data sets would build upon this. As Williams (2021, p.79) notes, social scientists 'aim to tell plausible stories'.

Not all themes emerging from the data were made prominent in its analysis. The data produced some learning related themes deserving of analysis which I chose not to pursue. One example was the discovery that, unprompted, some pupils had used the MoL post-it note system (itself a metacognitive process) to reflect not only on moments of learning about the substantive topic (rockets) but also metacognitively about their learning. Whilst tempting to include these unsolicited insights in the analysis, I decided since only one such MoL fed into an existing learning narrative to treat this theme as a possible future line of enquiry.

The next chapter presents the data resulting from the analysis described above.

6.0 Results

6.1 Organisation of Learning Narrative data and analysis

Results and analysis are presented in three narratives. Each narrative includes social network analysis (SNA) in the form of sociographs depicting interactive features of decentralised small group activity, a breakdown of interaction types from that small group activity and a timeline graph showing when critical learning incidents occurred and how tangible the learning was in each. Critical learning incidents are described and relevant data from other sources (interviews, MoL, additional video observations and researcher field notes) are presented in the form of transcripts and additional sociographs to evidence narratives, antecedents and possible causal chains of the learning. Stills from relevant video data are used to aid the reader. Each narrative ends with analysis of likely antecedents of learning and a summary interpretation using a CAS lens. Narrative three contains just one small group sociograph, whereas narratives one and two contain a second sociograph depicting events which followed on from the first.

This chapter begins with a presentation of graphic representations of the three main organisational structures evident during the research week. Narratives one to three follow this. The chapter ends by summarising key findings and highlighting points for discussion in Chapter Seven.

6.1.1 Classroom system context: Mapping different organisational features of the learning context

During the research week teaching and learning fell organisationally in three distinct structures: centralised (Figure 6.1), decentralised (Figure 6.2) and distributed (Figure 6.3), (similar to Davis and Sumara, 2006). Whilst learning was not organised by curriculum subject and there were no distinct lessons, in any given one-hour period pupils experienced all three structures, often multiple times. However, most time was spent in the decentralised (small group) structure (Figure 6.2).

The centralised structure (Figure 6.1) involves transmission from the teacher to all pupils simultaneously. Pupils were usually sitting on the carpet area, facing the teacher and the interactive whiteboard. The teacher interacted with all pupils simultaneously. Whilst there was interaction, this centralised approach was dominated by top-down transmission and teacher led dynamics.

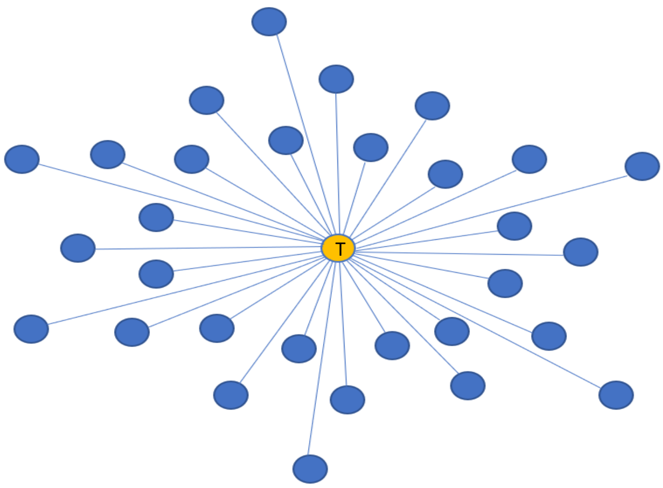


Figure 6.1 Illustrative mapping of whole class centralised (top-down structured – *adapted from Davis and Sumara, 2006*).

In the decentralised structure (Figure 6.2), pupils operated in small groups within the class zone whilst maintaining open lines of communication with the teacher, who adopted a less centralised role. Pupils exercised higher degrees of autonomy than the centralised model allowed, and the teacher circulated, contributing to group discussion, or made himself available for pupils to approach. Groups often operated without any teacher interaction. There was also a degree of cross-fertilisation and collision of ideas between groups. However, most interactions occurred within groups with only limited inter-group connections. With a mix of top-down and bottom-up dynamics, this model was a hybrid of the centralised and distributed structures.

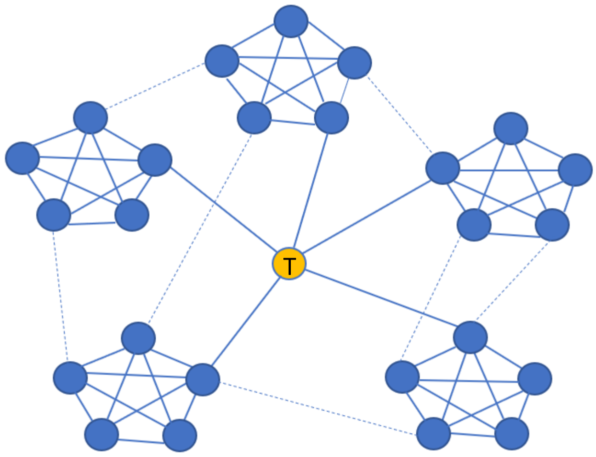


Figure 6.2 Illustrative mapping of whole class decentralised structure (hybrid - *adapted from Davis and Sumara, 2006*).

The distributed structure (Figure 6.3) was characterised by high interactive and movement autonomy. The teacher circulated among groups or took up a central position as in the decentralised model, however unlike the decentralised model, boundaries between pupil groups were loosely defined and interactions freely crossed group boundaries. Individuals moved far from their working group tables and the magnitude of total interactions was considerably higher than for the other two models. Unlike the other two models, the distributed structure was not initiated by teacher design. Rather, it was a consequence of the breakdown of the decentralised structure over time. As such, episodes of distributed activity tended not to run for very long before the teacher re-established either a centralised or decentralised structure.

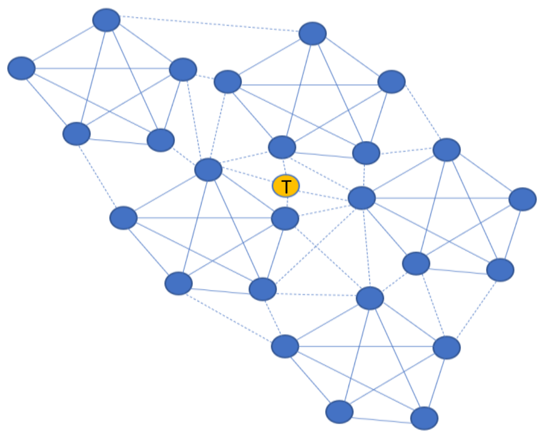


Figure 6.3. Illustrative mapping of whole class distributed structure (bottom-up emergent - *adapted from Davis and Sumara, 2006*).

As a result, the longest episodes of activity each day followed the decentralised structure, which was punctuated by shorter episodes of centralised and distributed activity. Most of the results which follow draw on episodes of decentralised group work, with smaller contributions from centralised and distributed episodes.

Results are presented below in three separate learning narratives. Each narrative begins with social network analysis (SNA) sociograph of a decentralised group work episode. Features of this episode are described, analysed and critical learning incidents identified. Data from the learning wall, from pupil interviews and from other videoed episodes are then drawn upon and triangulated to explore possible antecedents and consequences of the critical learning incidents. Beginning with decentralised group episodes and working outwards towards other data sources resulted in the three narratives presented in this chapter.

6.2 Learning Narrative 1

Monday (episode A) 18 mins 50 secs

Pupils: 10, 12, 24

Context: Mid-morning of the first day of the research week. Pupils were situated at a table on the edge of the classroom and had two computer tablets, paper and writing equipment. They were undertaking a task to create a poster explaining what aerodynamics means.

6.2.1 Social network analysis.

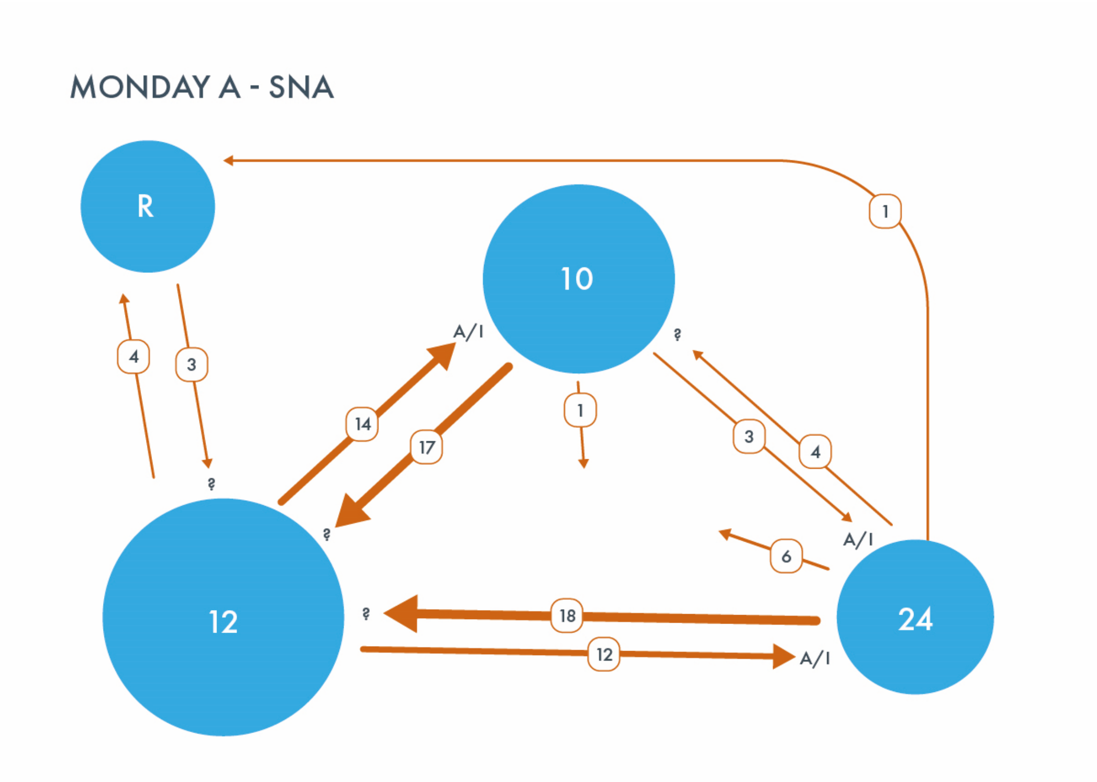


Figure 6.4 Sociograph of Monday episode A interactions. Arrows indicate direction of interactive utterances. The researcher (R) joined the group for the final few minutes. Arrows to the centre indicate utterances which had no identifiable individual recipient. Question marks indicate that interactions were questions and answers. A/I indicate answers or instructions.

Pupil	In-degree	Out-degree	Net in-degree	Connectivity *(n=3)*	Presence adjustment	Significance adjustment	Influence ranking
12	38	30	**+8**	*n*=3	-	-	**1**
10	18	21	**-3**	*n*=2	-	-	**2**
24	15	29	**-14**	*n*=3	-	-	**3**

Table 6.1 Factors determining relative nodal influence

In this episode no adjustments were made for connectivity, presence or significance since net in-degree data was indicative of group influence. Degree centrality centred around pupil 12 who was the most influential member, with a net in-degree of +8. Most interactions were filtered through pupil 12, representative of the fact that pupils 10 and 24 looked to pupil 12 for guidance and direction throughout. Pupil 24 had the least influence on the system with a net in-degree of -14. Pupil 10's net in-degree of -3 indicated that his influence on the system was more or less balanced with its influence on him. Most interactions were between pupils 10 and 12. Interactions from pupil 10 to 12 were mostly questions [?] and from 12 to 10 mostly answers or instructions [A/I]. All interactions emanating from pupils 10 and 12 were purposefully directed at another pupil. However, pupil 24 made utterances not clearly directed at either 10 or 12, which were ignored. Pupil 12 was the main interaction hub in the triad, directing the procedural activity and sharing knowledge. Pupil 12 was by far the most salient member.

Although not a precise measure, in addition to indicating degrees of system influence, degree-centrality also provides clues as to the status of nodes, and when triangulated with close observation of video footage was a useful point of reference for determining the source of a node's salience to the group, i.e., social or knowledge-based. In this episode the source of pupil 12's influence appeared to be knowledge-based, as pupils 10 and 24 deferred to him throughout on matters of knowledge, understanding and procedure. Pupil 10 appeared to have greater social salience, though this was subordinate to pupil 12's knowledge-based salience in this instance.

6.2.2 Interaction type proportion.

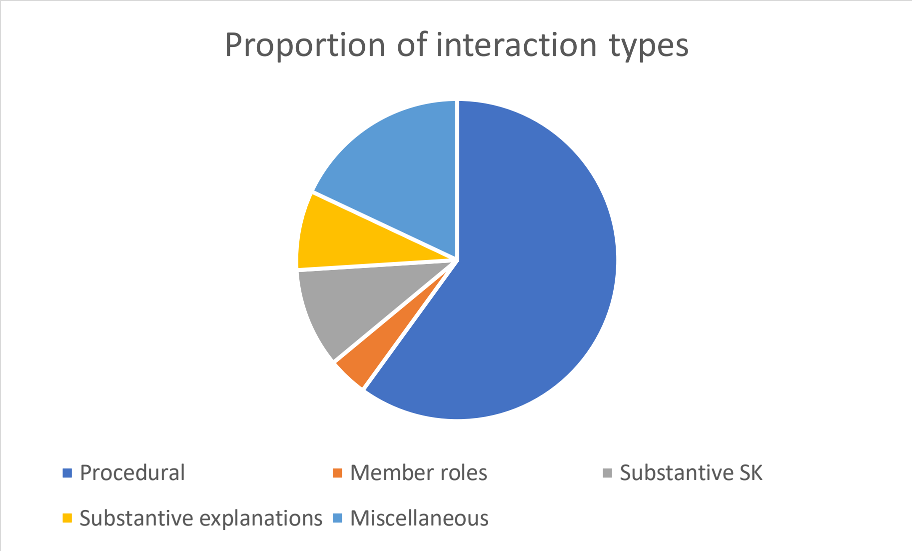


Figure 6.5 Episode Monday A group work proportionality of interaction type.

60% of interactions were procedural [concerning what to do]

4% of interactions related to group member roles [concerning who would/should do what]

10% of interactions related to substantive subject knowledge [questions/answers/suggestions]

8% of interactions were explanations about the substantive topic [of which 100% were elicited by the researcher]

0% of interactions were social conflict [arguments]

18% of interactions were miscellaneous [utterances spoken to self, irrelevant or inaudible utterances]

This data illustrates that a significant proportion of the 18:50 minute episode (82%) represented non-learning related (procedural, member roles, miscellaneous) interactions. The sparsity of learning-related interaction can also be seen in Figure 6.6, which shows that a full 11 minutes passed before the first notable learning incident occurred.

6.2.3 Critical Learning Incidents.

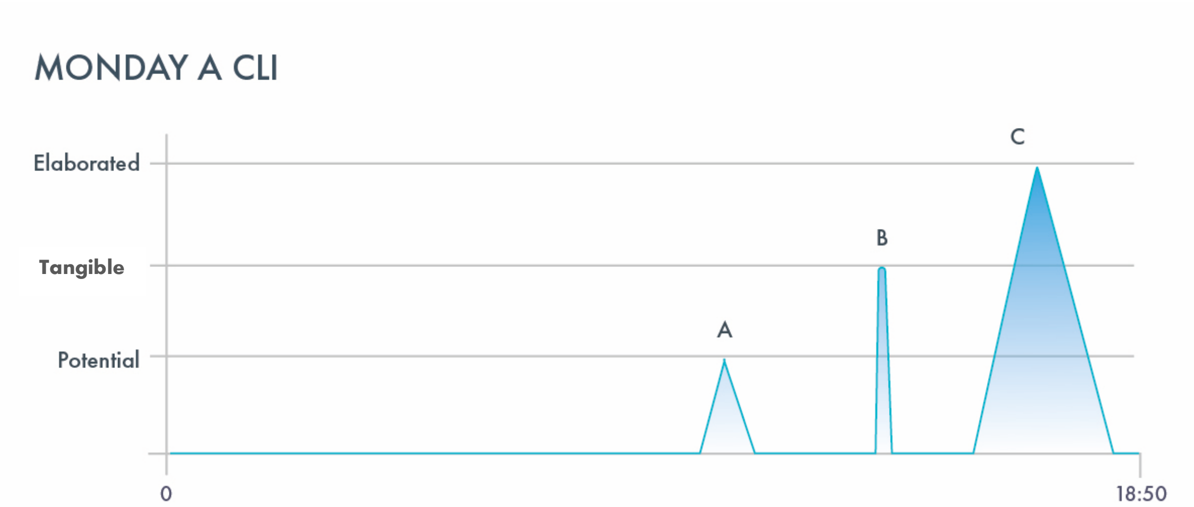


Figure 6.6 Critical learning incidents in episode Monday A.

Figure 6.6 depicts the three critical learning incidents during group work episode A. Interactions were dominated by procedure (Q & A about what to do, how to do it, instructions, distribution of roles etc). As implied by the in-degree/out-degree data, any learning which occurred was mediated through pupil 12. Evidence of learning included retrieval from online sources, explanation from pupil 12 under teacher (T) questioning and the use of technical vocabulary.

6.2.4 Critical Learning Incident Vignettes

At 10:49 (Figure 6.6 critical learning incident A) pupil 10 discovered a website function on the tablet which spoke the word ‘aerodynamics’. He pressed the button repeatedly for 30 seconds and mouthed the word, mimicking the adult voice. Pupils 24 and 12 joined in mouthing the word whilst mimicking the intonation of the computerised voice. All three were laughing and clearly viewed this incident as subversive. The incident ended when pupil 12 said *“we’re being filmed, come on”*.

This short episode is illustrative of how learning can be reinforced through unexpected, bottom-up occasioning, in this case through member personality and humour. Earlier in the video the term 'aerodynamics' had been the topic of conversation, with pupil 24 struggling to pronounce it, pupil 12 asking how to spell it and pupil 10 reading the spelling out loud. What the pupils clearly viewed as subversive behaviour, actually served in some small way to reinforce a key technical vocabulary term. This episode was categorised as a potential learning moment.

Figure 6.7 Pupils 24, 12 and 10 during episode Monday A

At 13:05 (Figure 6.6 critical learning incident B) Pupil 12 announced *"Oh, that's what stability is"* having spent the last few moments reading from a webpage. This was one of a few moments during the episode in which clear evidence of learning emerged. It was evident that pupil 12 had gained new knowledge in this moment, though no interactive antecedents to this learning were evident. Interestingly, pupil 12 did not share what he had learned with pupils 10 and 24, perhaps because of the obvious status dynamic. Later, pupil 12 explained what they had learned to the researcher. This can be described as a tangible, though not elaborated, learning moment.

At 14:00 (Figure 6.6 critical learning incident C) I joined the triad and asked questions, eliciting explanations from the pupils. I began by asking *"how's it going"?* to which pupil 12 immediately responded by explaining what they had been doing and what they planned to do next. The following exchange then occurred. Pupil 24 tried to contribute but allowed pupil 12 to take over. Pupil 10 did not contribute to this exchange.

Researcher: What do you think it means for air to flow over a rocket?

Pupil 24: (gesturing with hand) Sort of like, sort of like….

Pupil 12: (interrupts) It's stability.

Pupil 24: So it can go through it? So it can go a bit like faster or something?

Researcher: Hmmm

Pupil 12: It means stability.

Researcher: (to pupil 12) Tell me more.

Pupil 12: Stability is what keeps it from wobbling, so the wings create stability while the nose takes away drag.

Researcher: Oh OK. And what's drag?

Pupil 12: Drag is something that slows it down (motions with hand). So for example, if I was to put this on the front of the rocket (picks up flat piece of paper) it would slow the rocket down 'cause it's higher drag. If it was to be pointed, that would have less drag, so then the rocket would go faster (motions with the paper).

Researcher: Oh OK, so more drag slows you down, less drag speeds you up?

Pupil 12: yeah.

This episode illustrates how evidence of learning tends to remain beneath the surface until elicited through questioning. The knowledge and understanding demonstrated by pupil 12 had not surfaced until this point in the group work. The exchange lasted exactly 2 minutes, meaning that almost all evidencable learning surfaced in approximately 10% of the episode's duration. This can be described as an elaborated learning moment because the interaction was higher order (explanatory) and longer in duration than incidents A and B, however, it was elicited through top-down adult questioning.

6.2.5 Antecedents to learning

The only tangible learning came from pupil 12. Apart from the potential learning moment (A), neither pupil 10 or 24 gave any definitive outward indication of learning during the episode. On the surface it appeared as though pupils 10 and 24 were hindrances to pupil 12's learning. As the degree-centrality data illustrates, they were less influential and the video footage shows they were also heavily reliant on him. They asked him a lot of questions and took minimal responsibility for group decision making or task completion. Based on this reading of the episode, it could be concluded that pupil 12 showed evidence of learning despite, rather than because of, pupils 10 and 24. However this can be analysed differently. It could be argued that passivity from pupils 10 and 24 in fact motivated pupil 12 (a point discussed in Chapter Seven). The extent to which pupils 10 and 24 learned and benefitted from the episode is difficult to determine, although the following day at 10:19am pupil 10 posted a Knowledge MoL stating he *had "learnt what aerodynamics means: Cut through the air"*. It is likely that learning incident C contributed directly to this learning, and possible that point A may have contributed indirectly.

Pupil 10 was subject to a range of episodes and experiences in the period between episode A on Monday morning and posting the MoL on Tuesday morning. These included more (not video captured) group work, whole class recapping and discussion as well as small group experimentation firing rockets. Within and between these structured activities a range of undocumented informal interactions would also have occurred. I can speculate that contributions from each of these experiences gave rise to the moment in which this learned/understood knowledge emerged, however the data collected does not enable me to trace it back to any single moment, or quantify the contributions made by each experience. This invisible characteristic of learning is discussed in Chapter Seven.

Pupil 12 also posted a knowledge MoL on Tuesday at 10:15am stating

> *"I found out that stability is preventing the rocket from wobbling. I found this out on the internet"*.

Whilst this MoL was posted 24 hours later, video evidence suggests that pupil 12's dialogue with the researcher (Figure 6.3 incident C) the day before contributed significantly to this unit of learning since at that point he explained at length what he conveyed more succinctly on his MoL post-it. It is that the learning was fully formed at point C in the group work and that pupil 12 delayed writing the MoL until the following day. However, it is likely that additional experiences in the intervening 24 hours helped this learning to crystalise and surface. When asked about this MoL in a follow-up interview on the Wednesday, pupil 12 responded

> *"I knew what drag meant but I didn't know what stability meant, so I clicked on stability and it went on to a different thing about stability and it said that stability is from the rudders, the rudders keep it from tumbling over and spinning around and stuff."*

In continuing to describe the moment, he continued

> *"I knew rockets needed two things, strength and stability, but I just didn't know what stability meant."*

When asked if any other group members were involved in this MoL pupil 12 responded *"just me",* correlating with the video evidence that pupils 10 and 24 had not directly influenced this learning. In response to questions about the sources of his knowledge and learning, pupil 12 indicated that he had out of school experiences related to his learning about drag and stability

Researcher: Did you already know anything about this subject before that?

Pupil 12: Not really. I knew rockets needed two things, strength and stability, but I just didn't know what stability meant.

Researcher: Okay. Prior to this week, did you have any previous knowledge about anything to do with rockets or flying?

Pupil 12: No.

Researcher: No?

Pupil 12: My dad's made me know on like boats that, you know, can have fighter jets go off it and stuff like that.

Researcher: Oh okay. Have you ever been on a plane?

Pupil 12: Yeah, I have been on loads of planes.

Researcher: Okay, so do you think it's possible that other things you've experienced outside of school may have helped you this week with your understanding about firing the rockets?

Pupil 12: Um probably not because I didn't do much really after school [inaudible 5:38].

In this exchange pupil 12 considers it unlikely that any of his extensive flying experiences, or help to understand aircraft carriers from his father, contributed to his learning about drag and stability in rocket flight during the research week. It seems likely however, that they will have exerted a residual influence. Both these MoL examples are illustrative of relevant characteristics of learning. Firstly, the delay between sources of learning and moments in which learning crystalises and surfaces. Secondly, that moments of learning emerge as a consequence of multiple actors (peers, adults), inputs (tasks, resources) and influences, including those from outside of the classroom.

Later the same day (Monday) pupils 10, 12 and 24 were joined by two additional group members, pupils 20 and 26, and were engaged in making a testable prototype rocket nose (Monday episode B below). They began working at a table in the shared open plan cloakroom area of the classroom where there was some conversation about ways of preparing the plastic bottle ready for launch. This period was largely characterised by miscellaneous interaction, a large proportion of which was off-task and included jostling for airtime. At 02:50 the group moved outside to test their prototype using the rocket launcher. In this section of the recording there was some discussion about the optimal angle at which to set the launcher, however this section is largely characterised by conflict, mostly concerning member roles.

6.2.6 Social network analysis

Monday (episode B) 8 mins 35 secs

Pupils: 10, 12, 24 20, 26

Context: This episode of interactive group work differed considerably from Monday A, approximately one hour earlier. It took place in two locations, both of which were busier, noisier and more open, with greater number of passing pupils. Two additional pupils (20 and 26) joined the group, a factor which changed the dynamic and type of interactions considerably.

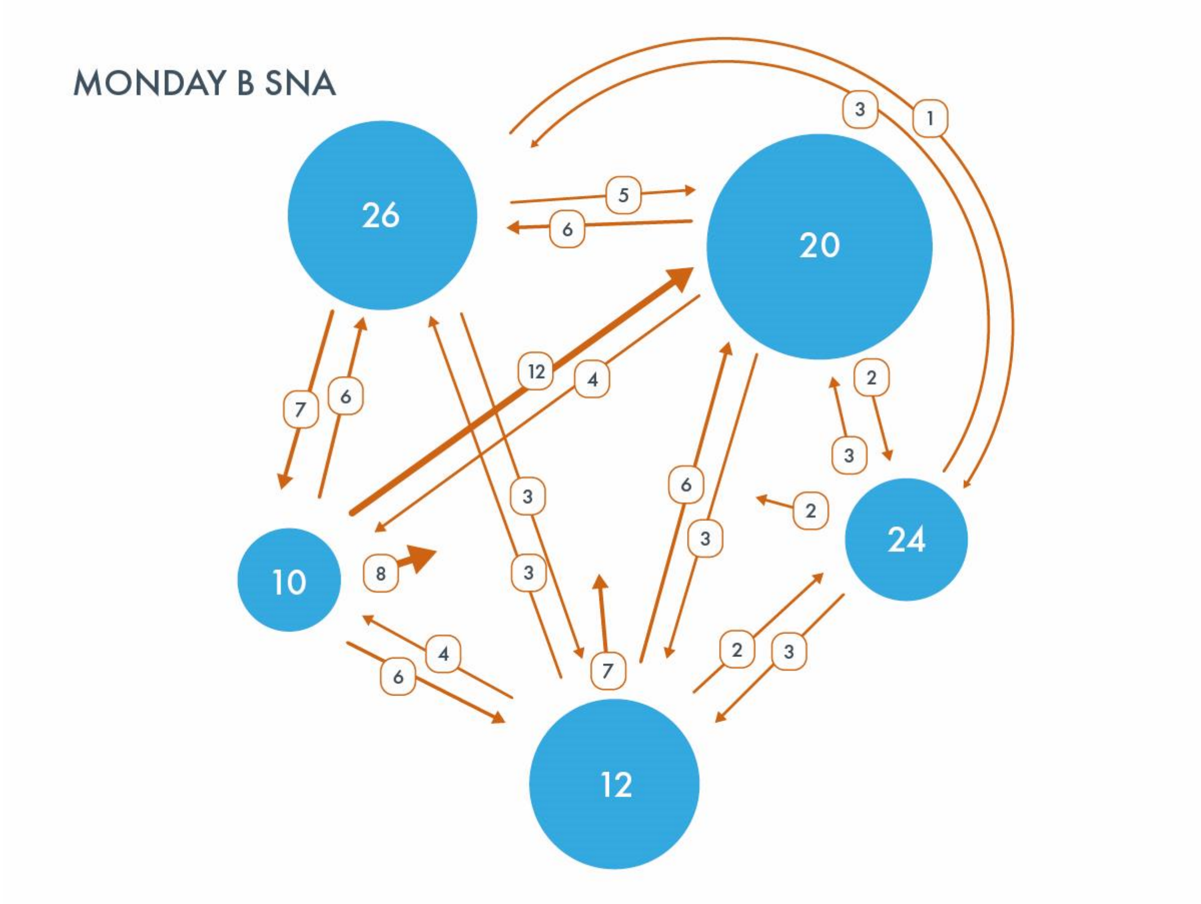


Figure 6.8 Sociograph of Monday (b) group work interactions.

Pupil	**In-degree**	**Out-degree**	**Net in-degree**	**Connectivity** *(n=4)*	**Presence adjustment**	**Significance adjustment**	**Influence ranking**
20	26	15	**+11**	*n*=4	-	-	**1**
26	18	16	**+2**	*n*=4	-	-	**2**
12	15	16	**-1**	*n*=4	-	-	**3**
24	5	11	**-6**	*n*=3	-	-	**4**
10	15	32	**-17**	*n*=3	-	-	**5**

Table 6.2 Factors determining relative nodal influence

As in episode Monday A, net in-degree alone presented an accurate representation of overall group influence in episode Monday B and no adjustments were made. Degree-centrality coalesced around pupil 20. Knowledge-based status remained significantly with pupil 12, however pupil 20 had high social status, which combined with apparent low conscientiousness resulted in him exerting a considerable and largely disruptive influence (net in-degree +11). This resulted in pupils 12 and 24 disconnecting from the group for a period of a few minutes (reflected in their influence rankings) during which time they interacted only with one another. Pupil 20's degree centrality is indicative of the way other group nodes (particularly pupil 10) were drawn to interact with him, with almost half pupil 20's in-degree interactions coming from pupil 10. Pupil 12, with a net in-degree -1, struggled to exert his influence on the system in this episode, making seven utterances to the group which received no response. Although he assumed a similar role to the earlier episode, he had a less captive audience for his procedural and subject knowledge contributions. Pupil 24 maintained a low level of influence within the system. Unlike the previous episode, in which pupil 12's degree-centrality contributed productively to the task, in this episode the considerable influence of pupil 20 had the opposite effect.

6.2.7 Interaction type proportion

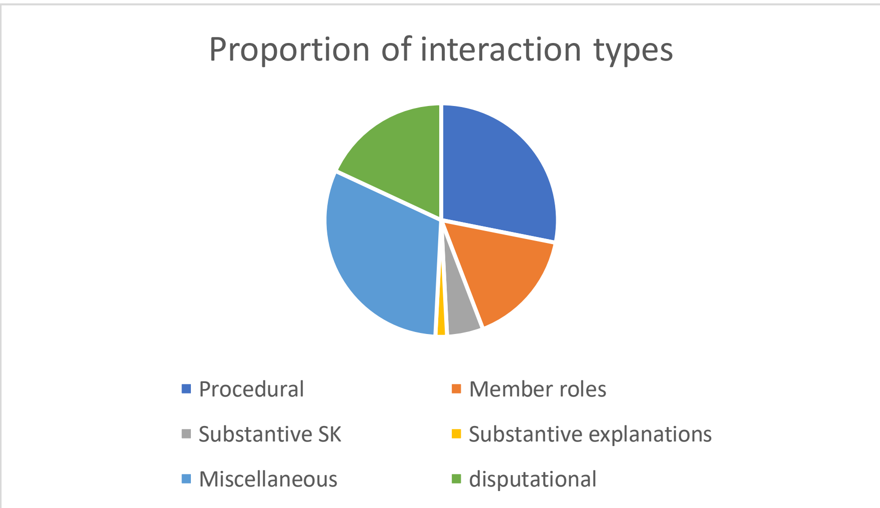


Figure 6.9 Monday B group work proportionality of interaction type.

28% of interactions were procedural

16% of interactions related to group member roles

5% of interactions related to substantive subject knowledge

2% of interactions were explanations about the substantive topic

18% of interactions were social conflict

31% of interactions were miscellaneous

The most significant difference between episodes Monday A and B was the injection of disagreement and conflict interactions, which was not present in episode A, but in episode B accounted for 18% of all interactions. Disputes were mostly about member roles, with a minority arising out of frustration over obstructive or unhelpful behaviours from some group members. Altogether, miscellaneous, disputational, role-related and procedural utterances accounted for 93% of interactions.

6.2.8   Critical Learning Incidents.

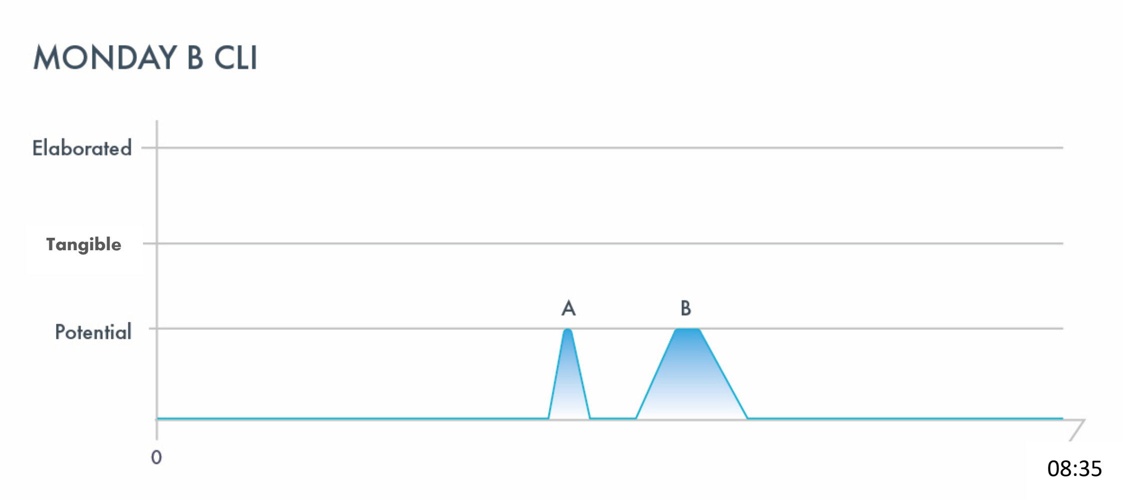


Figure 6.10 Critical learning incidents in episode Monday B.

Whilst pupil 12 was still the strongest procedural and learning influence on the group, the dominant social status resided with pupil 20 who appeared largely disengaged and intent on subverting the activities. All disputational and miscellaneous interactions during this episode flowed either directly or indirectly through pupil 20. In the first identifiable learning incident [Figure 6.10 critical learning incident A] the group were outside preparing to test a prototype rocket. Pupil 20 had assumed a role controlling the pump (despite remonstrations from pupils 10 and 24 that it was their turn) whilst pupils 12, 10 and 26 discussed setting the angle of the launcher (Figure 6.11).

Pupil 26: That's about 80 degrees
Pupil 12: 90 would go a bit high
Pupil 10: We should try 60 or 70
Pupil 26: I think we should do, yeah 60 or 70
Pupil 12: Good, OK, that's good.

Pupil 24 leaned over observing. The incident was followed immediately by one of many moments of group disagreement which spilled over into conflict.

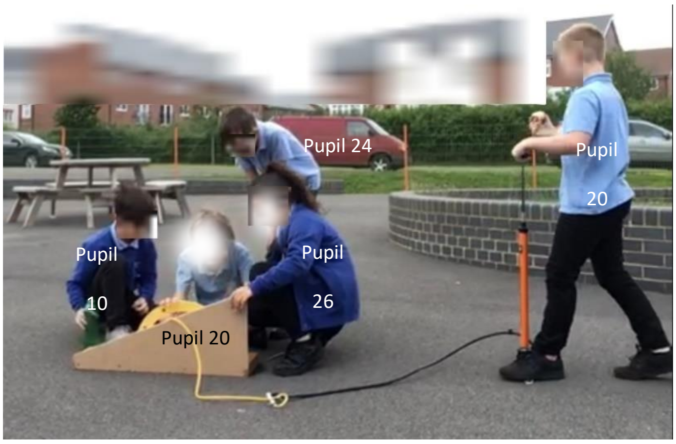


Figure 6.11 Still #2 from video Monday episode B. Critical learning incident A.

In this exchange it appeared that pupil 12 was the only group member who understood the relationship between launch angle and distance travelled. Pupil 10's suggestion that 'we should try 60 or 70' was in response to pupil 12's assertion that '90 would be a bit high', however it was not clear that pupil 10 understood why. This incident, which lasted approximately 20 seconds, was one of a number in episode Monday B in which pupil 12 had a positive effect on the thinking or knowledge states of other group members, hence its designation as a potential learning incident.

Figure 6.12 Still #1 from video Monday episode B. Critical learning incident A.

Shortly after setting the launch angle the rocket was fired. Amidst bursts of conflict about who should hold the metre stick and do the measuring, pupils 10, 12 and 20 engaged in a potential learning incident as they measured the distance travelled by the rocket [Figure 6.12, critical learning incident B]. The incident lasted just over one minute. Once again, pupil 12 was the leading influence. Meaningful verbal interactions were minimal. However, useful non-verbal interactions were evident as pupil 20 collaborated with pupil 12 to make repeated end-to-end metre stick measurements between the launcher and where the bottle landed. No tangible or elaborated learning was articulated, however pupils 10 and 20 appear to be engaged in a form of apprenticeship style learning by observing pupil 12's actions and joining in, occasionally being corrected by pupil 12. Potential learning occurring in this incident includes reinforcement of the principles of accurate measurement, skills associated with measuring accurately and concepts of quantification, estimation, and standardised units.

After this first test captured in the episode B recording, the group went on to test the same bottle repeatedly, each time containing different amounts of water.

Shortly after the rocket tests Pupil 20, whose only apparent period of focus and goal-directed engagement during episode B was the brief measuring incident described above, posted the following MoL on the Learning Wall (the MoL was scribed by an adult)

> *"I experimented by firing empty bottles, then with water in. I realised that measuring in cm and m was important to compare distance. I did this by using a metre stick".*

Here pupil 20 expressed his understanding of the need to use standard units of measurement to make valid comparisons between the distances travelled by the rocket when empty and when full.

6.2.9 Antecedents to learning

Although no direct verbal reference was made to comparing measurements by either pupil 20 or pupil 12, it seems evident that pupil 20 has aggregated his experiences of measuring multiple test-launches and inferred the importance of standardisation in the measurement process. The most obvious antecedent of this MoL is critical learning incident B, measuring the rocket distance, described above. The vignette suggests that Pupil 20 felt unable to engage with the 'science' content and so fell back on 'physical' activities that were in his comfort zone – working the pump and using the ruler – and which re-asserted his social dominance. Pupil 20 would have encountered the concept and act of measuring many times before, however the realisation articulated in this MoL is suggestive of a threshold moment in his understanding. On the available evidence, it seems likely that several features of the group system may have contributed to this learning, including group composition, the roles members assumed, their social status and even the conflict which it gave rise to.

In episode Monday A, pupil 12 exerted the most significant influence on the group network because of his knowledge and conscientiousness-based salience. In this episode, the strongest influence came from pupil 20, however his salience was due to social dominance. Interestingly, despite the distraction and subversion which this influence brought (which was clearly frustrating to pupil 12), it does also appear to have contributed to emergent learning. The following extract from the researcher field notes offers insight into relationships between pupil autonomy, social co-operation and learning.

Monday 17th June (morning – decentralised and distributed structures)

> *'A consequence of 'edge of chaos' style activity is that learning moments do not occur sequentially, but more randomly. Then they must be linked and connected coherently through questioning and distilling activities. Pupils do make discoveries and realisations through autonomous activity but require support deriving and articulating specific learning from them. Autonomous learning moments have a certain practical, goal-orientated utility in that they guide immediate and subsequent practical (trial and error) actions towards the goal (e.g. adjusting the amount of water in the bottle). However, for transfer of learning and learning which is not contextually situated a teacher in the structuring role is useful.'*

6.3 Summary and CAS analysis

In this narrative there is no question that learning emerged bottom-up. Aggregate behaviours moved outwards from salient pupils (12 and 20) through explanations and imitation as the group organised themselves (quite dysfunctionally at times) into roles and tasks. Pupils exerted and pushed back against conflicting forms of status locating roles and relationships in respect of one another. Social dynamics and pupil salience exerted considerable influence on task-orientation, productivity and learning. Evident learning was not a direct consequence of teacher input or control. Diversity of knowledge, status, conscientiousness and determination within the group system prompted unpredictable behaviours from members which the group had to accommodate, manage or work around. These behaviours had some negative influences on learning, but also occasioned opportunities which might otherwise not have arisen, demonstrating how emergence can inject novelty, which gives rise to change. In episode B, the group unarguably knew and understood more at the end of the episode than at the beginning, but not because of top-down control. There is sufficient evidence to infer with some confidence that conflict and chaos occasioned learning, though it is not possible to compare its quality or significance with learning which may have emerged in the absence of pupil 20's disruptive influence. Also evident in this narrative are accumulative, but non-linear, characteristics of learning. These are seen in the delays between sources and moments of learning, whereby multiple additive experiences in different contexts contributed to uneven progressions in knowledge and understanding. Potential learning arose from unlikely sources such as 'inappropriateness' and humour. It is noteworthy that during my interactions with the group in episode Monday A self-organised behaviours ceased, suggesting that conditions for emergence (autonomy, dense pupil interaction, pupil asymmetries) and the events they give rise to (perturbation, bifurcation, unpredictability, non-linearity, spontaneity) do not easily coexist with centralised teacher influence.

6.4 Learning Narrative 2

Monday (episode C) 5 mins 8 seconds

Pupils 11, 15, 16, 18, 19

Context: Pupils had a laptop each and were sitting round a table researching aerodynamics, internet searching, reading and talking about what they found. They were positioned on a table to one side of the classroom. The episode took place at the beginning of the afternoon session. Recording began approximately 10 minutes into the group work episode because the camera was moved to this table, from another table mid-session.

6.4.1 Social network analysis

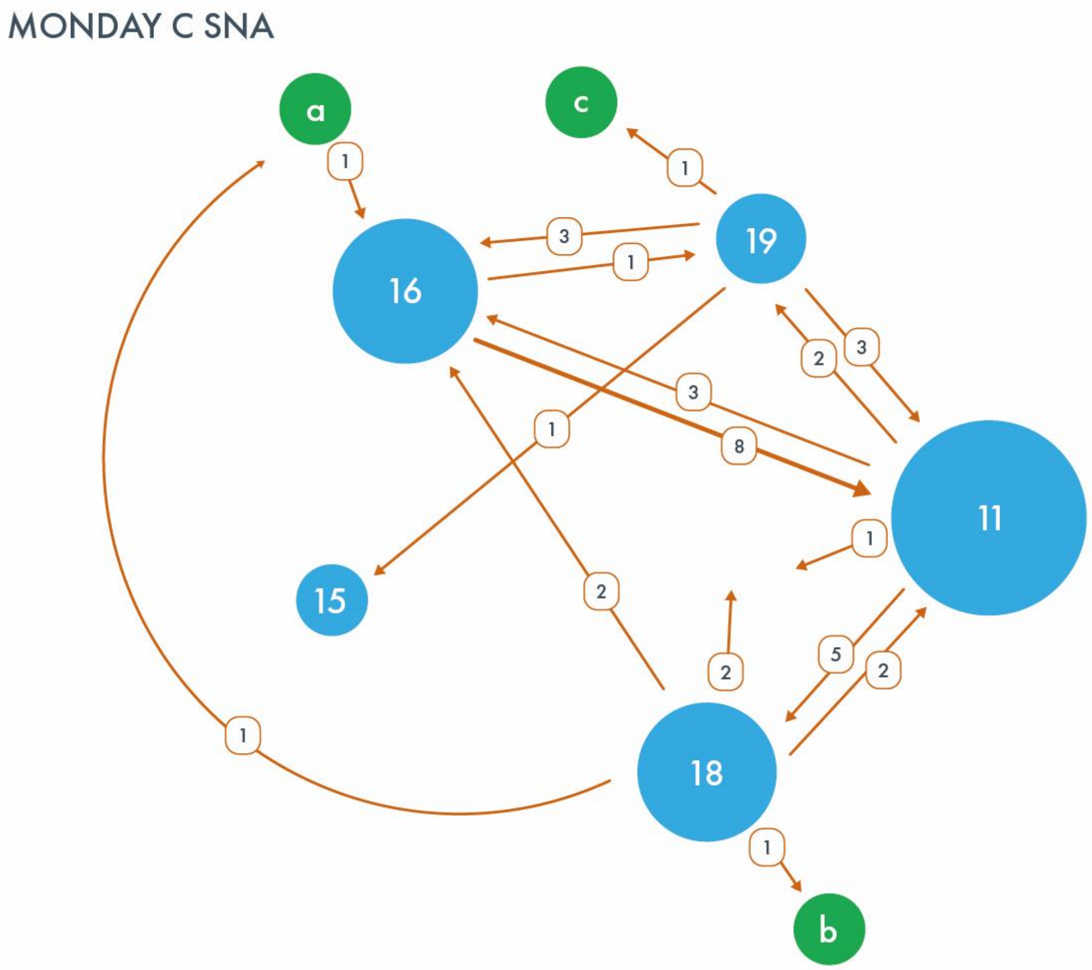


Figure 6.13 Sociograph of Monday episode C group work interactions. Green nodes represent pupils from other working groups who briefly interacted with pupils 16 and 18 during the episode. Arrows to the centre indicate utterances which had no identifiable recipient.

Pupil	In-degree	Out-degree	Net in-degree	Connectivity *(n=7)*	Presence adjustment	Significance adjustment	Influence ranking
11	13	11	**+2**	*n*=3	-	-	**1**
16	10	12	**-2**	*n*=2	-	-	**2**
18	5	8	**-3**	*n*=1	-	-	**3**
19	5	6	**-1**	*n*=2	↓	-	**4**
15	1	0	**+1**	*n*=0	↓	-	**5**

Table 6.3 Factors determining relative nodal influence

Overall, there were fewer interactions in this episode compared to Monday A and B, largely due to the nature of the activity, which involved undertaking internet research to contribute towards a group task. The range of net in-degree was also far narrower, with just five points between the lowest and highest, indicating that interactive reciprocity was fairly balanced. Pupils 16, 11 and 18 dominated interactions, accounting for 81% of all utterances between them, 40% coming from pupil 16 alone. Despite a net positive in-degree (+1) pupil 15 exited the group 48 seconds into the recording and did not return before the recording ended at 5 minutes and 8 seconds; this explains her minimal interaction and downward adjustment for her lack of presence. Pupil 19's influence ranking was also adjusted for presence since he exited the group, slightly later, at 2 minutes and 50 seconds.

In this episode degree centralisation is mixed. Of the five network nodes, three (pupils 11, 16 and 18) were responsible for most of the interactions. Of these three, interactions tended to centralise around pupil 11, with a net in-degree of +2. Pupil 11's out-degree was fairly evenly distributed between pupils 19, 16 and 18 indicating that although others tended to channel their interactions through him, he interacted quite evenly with three of the remaining four group members.

Analysis of the video recording suggests that pupil 11's salience was due to his social status. Pupil 16, whose utterances were dominated by miscellany, directed most of his interactions towards pupil 11. It was also evident that pupils 18 and 19 attempted to establish interactions with pupil 11 first, only directing their utterances elsewhere if pupil 11 did not respond. Pupil 19 appeared to have the consistently lowest influence on the group and all but one of his attempted interactions failed to get a response. However, he appeared to be high in conscientiousness and had an interesting idea to share about rocket design, discussed in section 6.4.4.

6.4.2 Interaction Proportion.

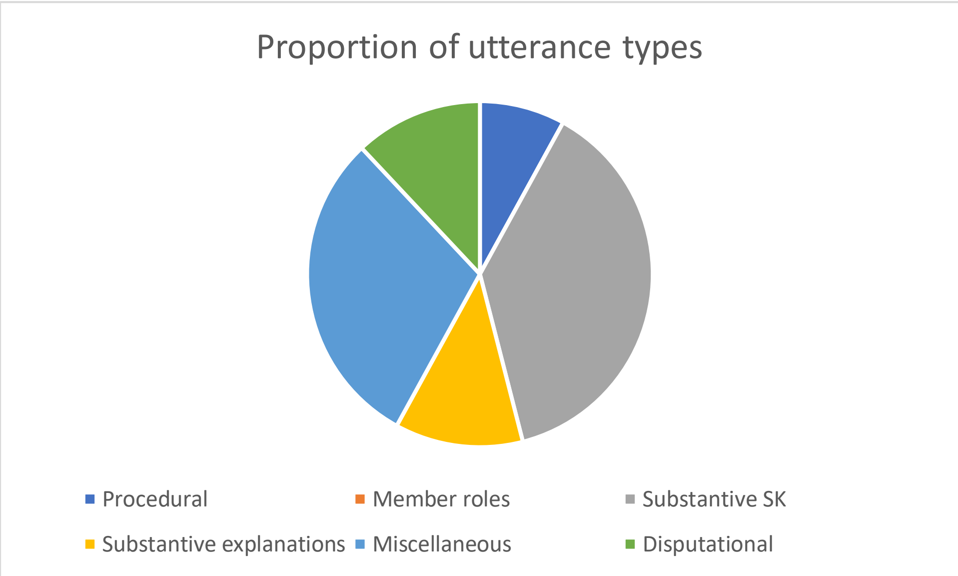


Figure 6.14 Monday C group work proportionality of interaction type.

8% of interactions were procedural

0% of interactions related to member roles

38% of interactions related to substantive subject knowledge

12% of interactions were explanations or attempted explanations about the substantive topic

12% of interactions were social conflict

30% of interactions were miscellaneous

Data indicate that compared with episodes A and B from Monday morning, episode C had a higher proportion of learning-related utterances. Unlike episodes A and B, the group had already begun collaborating when filming started, which is likely to account for the comparatively low proportion of procedural and member role interactions. Also contributing to the low proportion of member role interactions was the fact that although the pupils were working together, they were not required to share equipment. Of the 38% of utterances focussed on relevant subject knowledge, most were examples of pupils sharing things they had found out with a neighbour or the wider group. Instances of conflict were proportionally low and all occurred in a single dispute involving pupils 16, 18 and a pupil who approached and interacted from a different group (a). All miscellaneous utterances either came from, or were in response to, pupil 16.

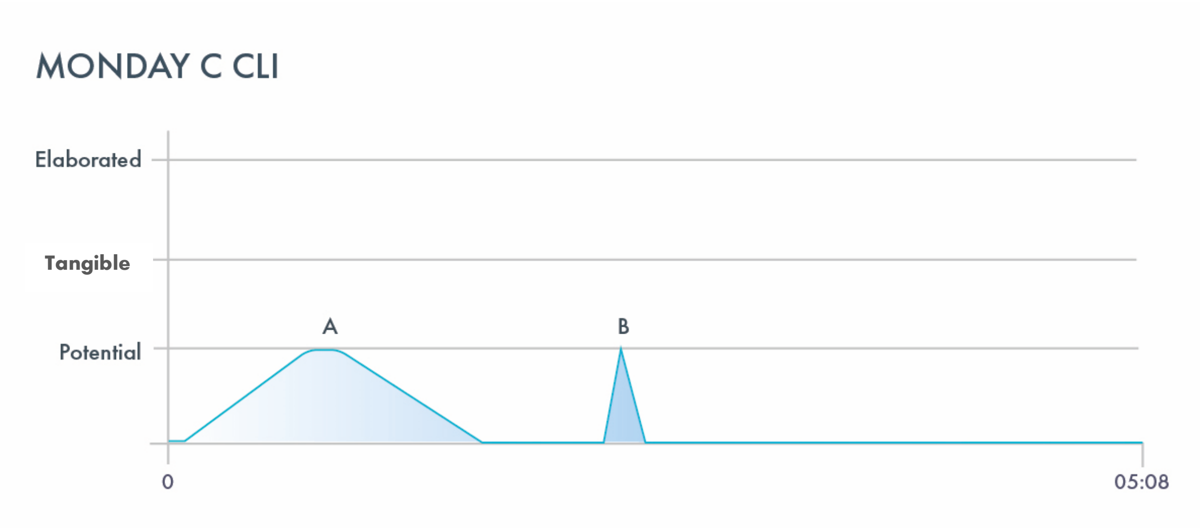


Figure 6.15 Critical learning incidents in group work video episode Monday C.

6.4.3 Critical Learning Incidents

This episode was less interactive than Monday A or B, largely because the pupils were engaged in internet research, each with their own laptop. However, the data does reveal some noteworthy illustrations of learning emerging from unexpected sources. Although this episode contained considerably more learning-relevant interactions than episodes A and B, and despite the proportion of non-task relevant utterances being notably lower, there were only two incidents judged to be critical.

6.4.4 Critical Learning Incident vignettes

Learning incident A (Figure 6.15, 00:19 minutes) is suggestive of learning on the part of pupil 19, but is highlighted more as a potential missed learning opportunity for the group. At the beginning of the recording pupil 19 had a sudden idea about joining two bottles together to make a rocket. This seemed to be based on his understanding that the greater the volume of water in the bottle, the further the rocket will travel when fired. Whilst this assumption was in fact only partially correct, the incident gives a window on pupil 19's reasoning. At 00:19 pupil 19 attempted to share and demonstrate his idea with pupil 11 (Figure 6.16) who showed no interest. At 00:25 pupil 19 tried to share his idea with pupil 15 who was also unresponsive (Figure 6.17). At 1:00 pupil 19 attempted to share his idea with a pupil from another group who is passing (c) but was again ignored. At 1:22 pupil 11 finally responded to pupil 19

Pupil 11: That's exactly what I tried to do

Pupil 19: Yes, when you do this, yeah *(puts two plastic bottles together end to end)*, you cut that bit off, then we can put the water in here *(gestures to the bottle top)* then fire it.

Pupil 11: *(No response)*

Apparently frustrated at being ignored, at 2:50 Pupil 19 left the table and went to the teacher to explain his idea (critical learning incident B). The teacher can be heard off camera listening to pupil 19's idea and discussing it with him.

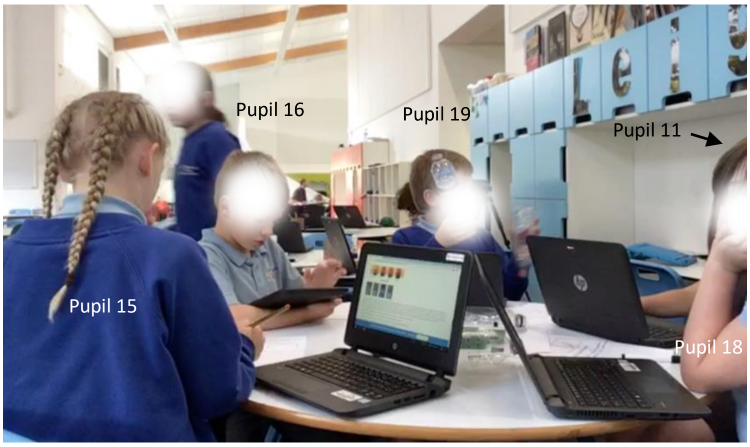


Figure 6.16. Critical learning incident A(i) – pupil 19 attempts to share his idea with pupil 11 (out of shot).

Figure 6.17. Critical learning incident A(ii) – pupil 19 attempts to share his idea with pupil 15.

Later the same afternoon, at 2:05pm, pupil 19 added a MoL note to the learning wall. The MoL was designated as a realisation and read

"I realised that if you stick two bottles together and have filled it up it will go further".

It would be more accurate to say that pupil 19 hypothesised this, rather than realised it. At 2:50 minutes, having had little success sharing his idea to join two bottles to add more water to the rocket with his group, pupil 19 circumvented the group and can be heard off camera explaining his idea to the teacher (Figure 6.15, Learning incident B). Whilst his actual explanation is inaudible, the teacher's responses indicate that pupil 19 explained what he had previously failed to explain and demonstrate to members of his group. A partial transcript of this interaction is shown below.

Pupil 19: Mr XXX (getting the teacher's attention), (explanation inaudible)

Teacher: Oh I see, so the two bottles get stuck together? That's really interesting, and how would you join them together?

Pupil 19: (inaudible response)

Teacher: That's a really interesting idea, have you written it down? (referring to a post-it note on the learning wall). Brilliant!

As a result, later that afternoon pupil 19 was offered the opportunity to share the idea with the rest of the class (Figure 6.18). A consequence of this moment on Monday afternoon was that multiple groups trialled the bottle joining idea the following day. This serves as a useful example of how learning at lower levels of the system, in this case at the level of the individual, can influence changes at higher levels, in this example at the whole class level.

Figure 6.18. Still #1 from video episode C. Monday 2:48pm. Pupil 19 shares his bottle joining idea with the whole class.

Pupil 19's apparent social status played a role in the learning depicted in this episode. As illustrated in Figure 6.13, the degree centralisation of the group network was quite mixed, with interactions largely dominated by pupils 11, 16 and 18, and pupils 11 and 19 interacting comparatively little. Pupil 19's net in-degree -1 indicates that he made more attempts to engage other pupils in the network than were attempted with him. In the first few minutes of the episode, he made several failed attempts to engage his peers with his bottle joining idea. Sociograph data and detailed viewings of the video recording illustrate that pupil 19 was unable to secure the interest or engagement of his peers or achieve uptake for his idea, indicative of low social acceptance. However, his failure to engage his peers appears to have prompted the interesting and unexpected decision to exit the group and engage the teacher. The following day (Tuesday) the same group collaborated on building their test prototype and were using pupil 19's idea to join two bottles together (episode Tuesday A below). The pupils were constructing their bottle rocket prototype, using bottles, card, scissors and tape. They had a nose cone fact sheet and most of the session was spent attempting to construct a 'parabola' style nose cone to attach to the rocket and test. The task had been set earlier for all groups by the Teacher (Figure 6.19). Data from this episode illustrate further influences and consequences arising from pupil 19's actions.

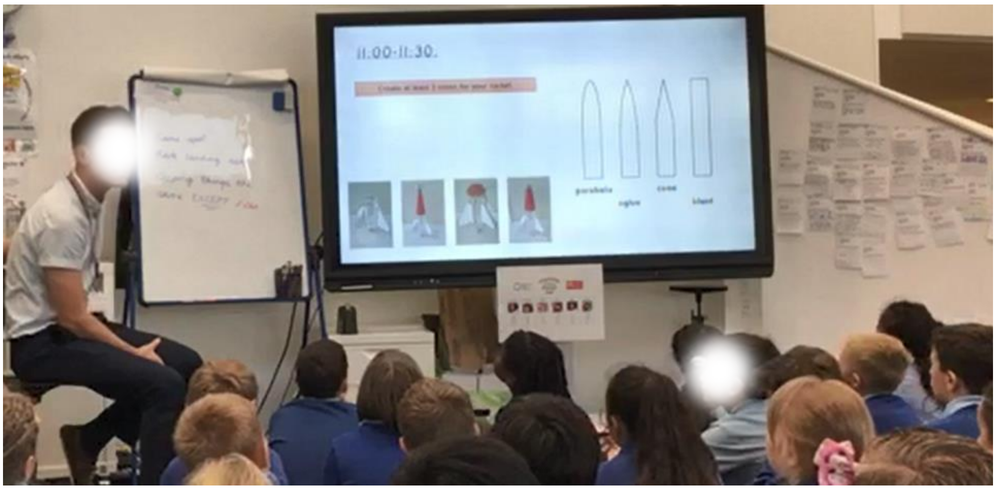


Figure 6.19 Teacher setting group task to construct and test different types of nose cone. Tuesday am.

Tuesday (episode A) 20 mins 8 seconds

Pupils 11, 15, 16, 18, 19

Context: The same group as episode Monday c collaborated on building their prototype rocket, implementing pupil 19's idea. They were positioned round a table in the classroom.

6.4.5 Social network analysis

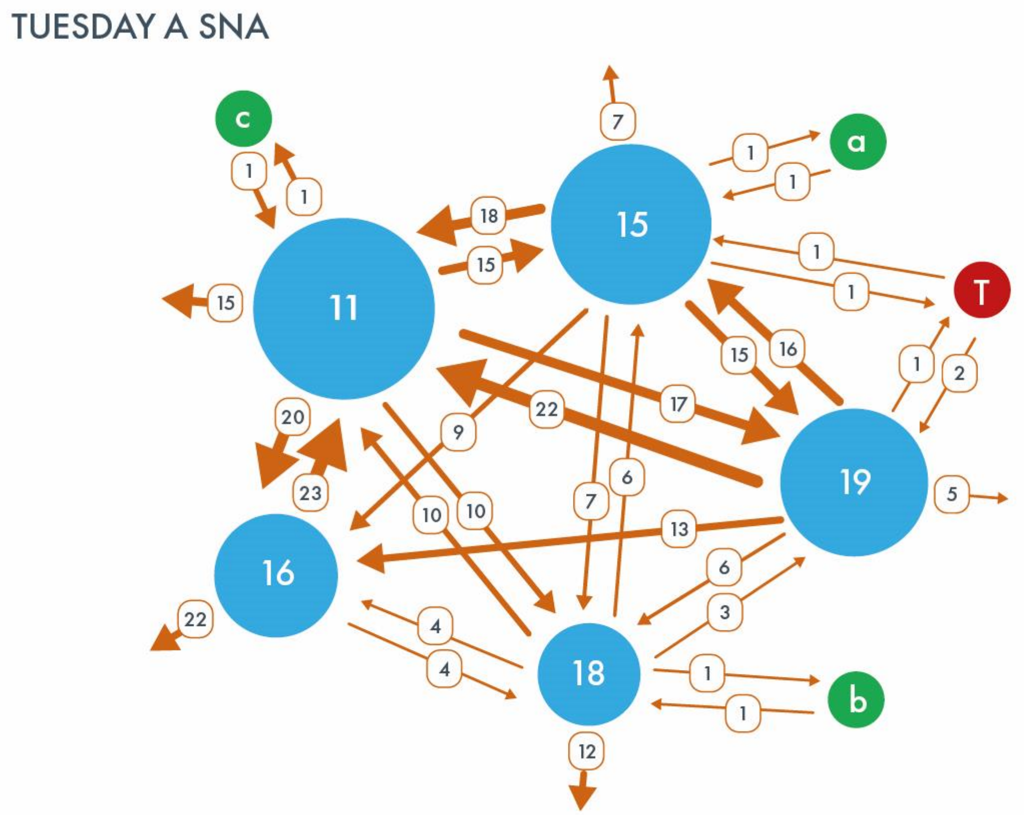


Figure 6.20 Sociograph of Tuesday A group work interactions. Green nodes represent pupils from other working groups who briefly interacted with pupils 11, 15 and 18 during the episode. Arrows to the outside indicate utterances which had no identifiable recipient or were intended for the group.

Pupil	In-degree	Out-degree	Net in-degree	Connectivity *(n=8)*	Presence adjustment	Significance adjustment	Influence ranking
11	74	78	**-4**	*n*=5	-	-	**1**
15	39	58	**-19**	*n*=5	-	↑	**2**
19	37	63	**-26**	*n*=4	-	↑	**3**
16	46	49	**-3**	*n*=2	-	↓	**4**
18	28	36	**-8**	*n*=5	-	↓	**5**

Table 6.4 Factors determining relative nodal influence

Degree centrality in this episode coalesced again around pupil 11 who had a net negative in-degree of -4. Whilst not surprising that pupil 11 was again a hub for interactions, pupil 19, having interacted little during the group's previous episode, spoke up and was listened to more in this episode. Whilst he had the lowest net in-degree (-26), the significance of his utterances amplified his overall influence ranking. An explanation for this is that following his actions the previous day, circumventing his group, explaining his idea to the teacher and eventually to the whole class, the group had adopted pupil 19's rocket design idea. This elevated his status which appeared to increase his confidence and assertiveness as other group members consulted with him about the design. As in the previous episode, pupil 16's interactions were dominated by miscellaneous and off-task utterances and though his net in-degree appears to make him most influential (in-degree -3), adjustments for significance of utterances and connectivity diminished his overall influence ranking. Also of note is pupil 15's increased centrality to the group. In the previous episode she interacted very little and exited the group after 48 seconds. This time she interacted continuously, taking responsibility for keeping other group members on task, directing members and sharing subject knowledge. Her net in-degree does not appear influential, however adjustments for significance are representative of the fact that the group depended on her a lot. As in this group's previous episode, pupil 18's influence was quite low (net in-degree -10) with almost 50% of her utterances not being directed at anyone specific or being listened to. Despite not having the lowest net in-degree, adjustment for significance gave her the lowest influence ranking.

6.4.6 Interaction type proportion.

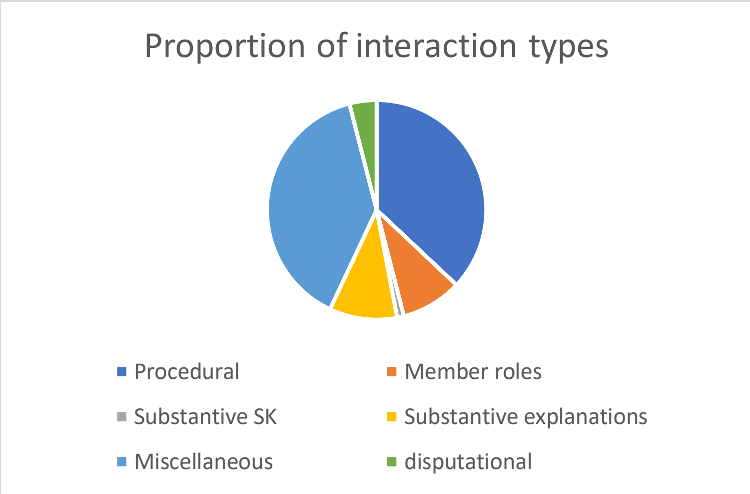


Figure 6.21 Tuesday A group work proportionality of interaction type.

37% of interactions were procedural

9% of interactions related to group member roles

1% of interactions related to substantive subject knowledge

10% of interactions were explanations about the substantive topic

4% of interactions were social conflict

39% of interactions were miscellaneous

The data shows that this episode was dominated by interactions not directly related to learning. Procedural, member role, disputational and miscellany account for 89% of interactions, with only 11% of exchanges pertaining directly to knowledge and understanding. These figures are potentially misleading, however. Many of the procedural utterances about what to do were indicative of learning. For example, discussions about how to shape the rocket's nose cone, about which materials to use and concerning decisions about which way round to fire the bottle indirectly revealed pupils' reasoning about aerodynamics, power to weight ratios and the need for an airtight seal at the bottle opening. Much of the learning evident in this episode therefore was implicit within procedural utterances.

6.4.7 Critical incidents

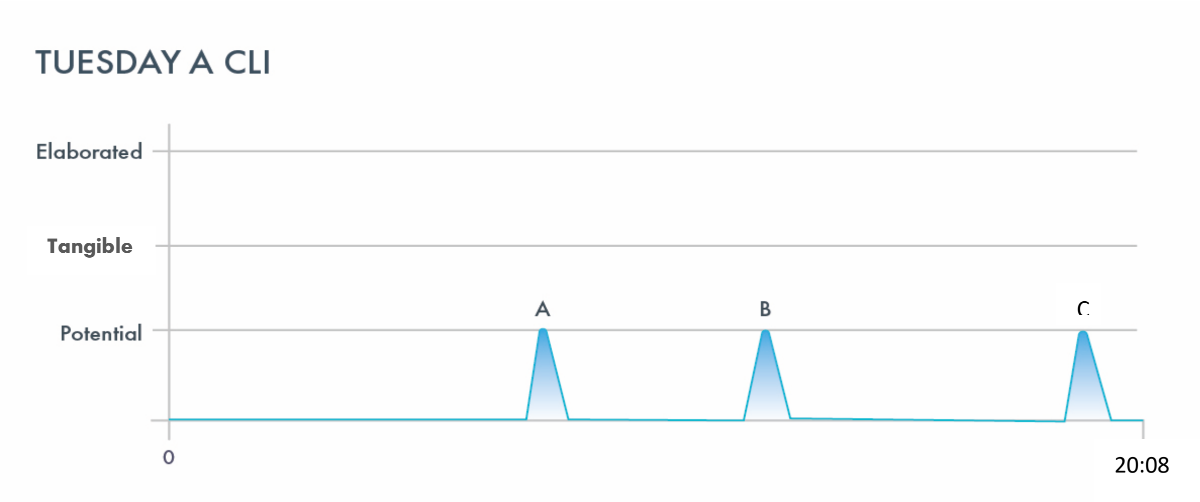


Figure 6.22 Critical learning incidents in group work video episode Tuesday A.

6.4.8 Critical Learning Incident Vignettes

There were no obvious tangible or elaborated incidents of learning in this episode, despite its length. Several the procedural interactions showed evidence of prior knowledge and understanding coming from individuals (particularly pupils 11, 15 and 19), though on these occasions there is little evidence of uptake by other members of the group. However, three incidents of potential learning did occur.

Figure 6.23 Still #1 from video episode Tuesday A showing pupils 16, 11, 15, 19 and 18.

In critical learning incident A (Figure 6.22, 8:18 minutes) with pupil 19 having joined two bottles together to make the body of the rocket, pupil 15 placed the prototype nose cone onto it and the following discussion ensued.

Pupil 15: We need to put this on here (places nose cone onto rocket)

Pupil 16: It needs to be smaller

Pupil 15: No, it needs to be bigger

Pupil 11: Bigger? You need me to make it bigger? Why didn't you tell me that in the first place?

Pupil 19: And it needs to go down to at least there (gesturing halfway down the bottle) and up to at least there (gesturing how far the nose should protrude).

Pupil 19: Are you sure the parabola nose is the best?

Pupil 15: Yes. It flies for longer (consulting fact sheet), but I don't think it will be the most aerodynamic, I think the pointy one will be.

In this exchange a series of individual judgements from pupils 16, 15 and 19 reveal their reasoning about the suitability of the nose cone. Although their actual reasoning remains tacit, it is evident that the activity has prompted them to question, think logically and draw on sources of information about the function of a nose cone and the suitability of their chosen style. This passage also illustrates the role that disagreement and questioning between group members plays in decision making, resulting in pupil 15 justifying her idea to use a parabola style nose cone by referring to the fact sheet. In pupil 15's final utterance she appeared to wrestle with her own understanding of aerodynamics. Whilst she did not explain her thinking fully, her understanding that the more pointed an object is, the more aerodynamic it will be is challenged by the fact sheet, which states that the more rounded parabola nose travels through the air for longer.

In critical learning incident B (Figure 6.22, 12:20 minutes) pupil 11 expressed concern that the rocket would not be sufficiently aerodynamic because the surface of one of the two joined bottles is smooth and the other bumpy. This prompted a dialogue between pupils 11, 15 and 19 about how effective the nose cone will be.

Pupil 11: Do you think this is going to be aero…..I don't think it's going to work because look, clear (points to one bottle), bumpy (points to the other bottle).

Pupil 19: It's still going to work.

Pupil 11: How's it [the nose] going to stick down?

Pupil 15: It doesn't come off, look (pupil 19 thrusts rocket in the air a few times, after which the nose comes off).

Pupil 19: Just put a bit of tape on it so that we can actually get it off if we want to.

Pupil 16: Errr, where's the tape?

Pupil 19: This is a good parabola though.

This led into a short passage in which the pupils began to test the rocket by throwing it across the table to each other. The dialogue was all about whose turn it is, but the actions were concerned with evaluating the effectiveness of the new nose cone. It is clear from the video data that the pupils viewed throwing the rocket as inappropriate (pupil 15 pointed at the camera and reminded the others that they were being filmed), but something worth risking nevertheless, for the sake of experimentation. The potential learning here is reinforcement of the cause-effect principles of aerodynamics and problem-solving about how to prevent the nose cone from falling off. A first viewing of this short episode would lead to a conclusion that nothing significant was occurring, firstly because the reasoning behind the pupils' utterances remains tacit throughout and secondly because it evolves into subversive behaviour. However, closer observation, drawing on CAS framing and the interrogative questions (Section 5.1.2) as points of reference, reveals that a range of learning behaviours including reasoning, hypothesising, constructive disagreement, problem-solving and testing are evident beneath the surface. These features lack structure and are not fully formed or made explicit, however they may represent the building blocks of future elaborated articulations of knowledge and understanding.

Following this task, all groups went outside to test the different nose cone prototypes they had constructed.

Figure 6.24 Tuesday afternoon. Hand testing different nose cones.

Changes in pupil 19's social status had consequences for him individually and salience for the group system. Two days later, mid-morning on the Thursday of the research week, and after the group had tested their rocket prototype, pupil 19 added a MoL note to the learning wall which read *"It nose-dived because there was too much weight"*. When asked about this MoL in his interview pupil 19 reported that this realisation came whilst testing their prototype rocket outside.

Researcher: Right. So, tell me what was it that nose-dived and what was creating the weight?

Pupil 19: Well, the rocket nose-dived because there was too much weight, so it didn't go very properly, it just went like that (gestured falling motion with hand). So then for our last test we took some tape off as well and then we launched it with less water.

Researcher: And that was more successful, was it?

Pupil 19: Yeah.

Researcher: Was that your 10.59 (metre) one?

Pupil 19: Yeah.

Researcher: And how did it feel to have realised something important about the weight?

Pupil 19: Um I think that when we realised that, on how much weight there was on the rocket and careful you have to be.

Researcher: Okay. What things made you make that realisation do you think?

Pupil 19: Um the thing that made me realise that was err, I don't know. I was doing the measuring.

Researcher: Doing the measuring, right. So, what was the moment where you thought, aah, the water is the problem?

Pupil 19: Um probably at the second test.

Researcher: Okay.

Pupil 19: But then I thought that it must have just been an accident. The fourth test I realised that it was the weight.

Researcher: I see, and that was by watching what the rocket did?

Pupil 19: Yeah.

Pupil 19 eventually came to a useful understanding that his initial hypothesis (the greater the volume of water the greater the distance of travel) was incorrect, or at least only partially correct. As demonstrated in the interview transcript above, this realisation came through testing. Also evident in this interview excerpt are the limits on pupil 19's access to insights about his own learning. Without the probing effect of the questioning, it is apparent that his awareness of how he arrived at his eventual conclusion would have remained tacit. This has methodological implications (discussed in Chapter Three) and is suggestive of the important role which metacognitive mechanisms play in learning and contributions teachers make to their application.

In critical learning incident C (Figure 6.22 19:30 minutes) pupil 15 recorded a MoL on a post-it and exited the group to add it to the learning wall. The MoL read

> *"I realised that a parabola is one of the trickiest nose (cones) because there is a hole at the top, so you have to cover it. I learned this when making the nose".*

Whilst not an example of subject knowledge or conceptual learning, this MoL is among a number which reveal metacognitive monitoring and judgements of learning. In this instance, pupil 15 presented an ease of learning reflection (Dunlosky, 2010) about the task she had undertaken. This metacognitive MoL is consistent with utterances made by pupil 15 at various points during the episode.

Pupil 15: (00:54 minutes) I don't know how they make that shape into a nose.
Pupil 15: (01:04) Shall we not have that one (parabola nose shape)? It's hard.
Pupil 11: (05:35) How are we going to make this?
Pupil 15: 05:38) I know, it's hard…. (inaudible).
Pupil 15: (08:58) Can someone help me glue this down?
Pupil 15: (09:43) Errr…this is not going well.

6.4.9 Antecedents to learning

Once again, salience, social dynamics and personality played an influential role in group activity and learning. Pupil 19's low social stature was both an obstruction and facilitator of learning and eventually he became salient to proceedings. It is easy to imagine that the learning in this narrative would have taken a considerably different path with alternative outcomes had pupil 19 not chosen to bypass his group and approach the teacher (Section 6.4.4). This decision was influential on group activities, shaping decisions and elevating pupil 19's status to an extent whereby his influence on the group, and therefore the learning, also grew. Pupil 15's considerable contributions to episode Tuesday A, compared to Monday C, was also a significant influence. She was directly involved in all three critical learning incidents and her repeated attempts to maintain on-task focus, as well as time spent directing and discussing procedure with others contributed to productivity. Conscientiousness is a notable determinant here. Unlike pupil 12 in episode Monday B, who struggled to influence group productivity, despite his high conscientiousness, in the face of higher status peers, pupil 15's conscientious attitude exerted marked influence on proceedings. This was an example of a notably conscientious pupil also having sufficient determination for her conscientiousness to bear influence, and is illustrative that salience to group proceedings was fluid, not fixed.

This narrative also shows evidence of roles that questioning and disagreement play in creating conditions conducive to learning. Justification, reasoning and explanation all emerged during sequences of discussion; illustrative how pivotal disagreement can be in the construction of new knowledge and understandings. The most obvious antecedent of this is group diversity, including diversity of personality traits such as intra/extraversion and tenacity. Pupil 19's frustration at not being listened to and subsequent bypassing of his group in episode Monday C illustrates how unpredictability can be an antecedent to learning. Interestingly, this narrative also illustrates how misconceptions can be productive sites for learning. Pupil 19's hypothesis was actually based on a misconception, but the narrative suggests that pursuing and testing a misconceived idea actually resulted in useful learning which certainly transcended the individual knowledge of each member. Finally, pupil 15's metacognitive observations appear to result from the challenge posed by the task itself.

6.5 Summary and CAS analysis

A CAS lens reveals interesting insights into the events in this narrative. Firstly, as in narrative one pupil autonomy and patterns of self-organised peer dynamics were influential on events and learning. This was seen in pupil 19's decision to break away from his group and express his idea the teacher, a bifurcation which arose unexpectedly as pupils sent, received and responded to verbal and non-verbal signals. It disrupted the linearity of events, prompted abrupt changes in group decisions and perturbed the status hierarchy within the group, all of which had consequences for learning within the system. The fact that pupil 19's hypothesis was incorrect, but later corrected through experimentation illustrates that causation in eventual group learning was non-linear. This bifurcation also prompted information to transcend the individual level of the whole class system, initially bypassing the decentralised small group level. These events can well be described as emergent and part of the causal fabric of learning, though once again observable learning was only inferred and potential. The eventual learning, which moved through the small group and the whole class was discovered and developed through the collective, transcending the knowledge of any one group member.

6.6 Learning Narrative 3

Tuesday (episode B) 17 minutes 50 seconds

Pupils: 4, 13, 17, 25, 29

Context: Pupils were discussing and creating wing designs for their prototype rocket. The group had previously created and tested different nose cones. The recording ended before they had completed making and fixing their wings to the rocket.

6.6.1 Social network analysis.

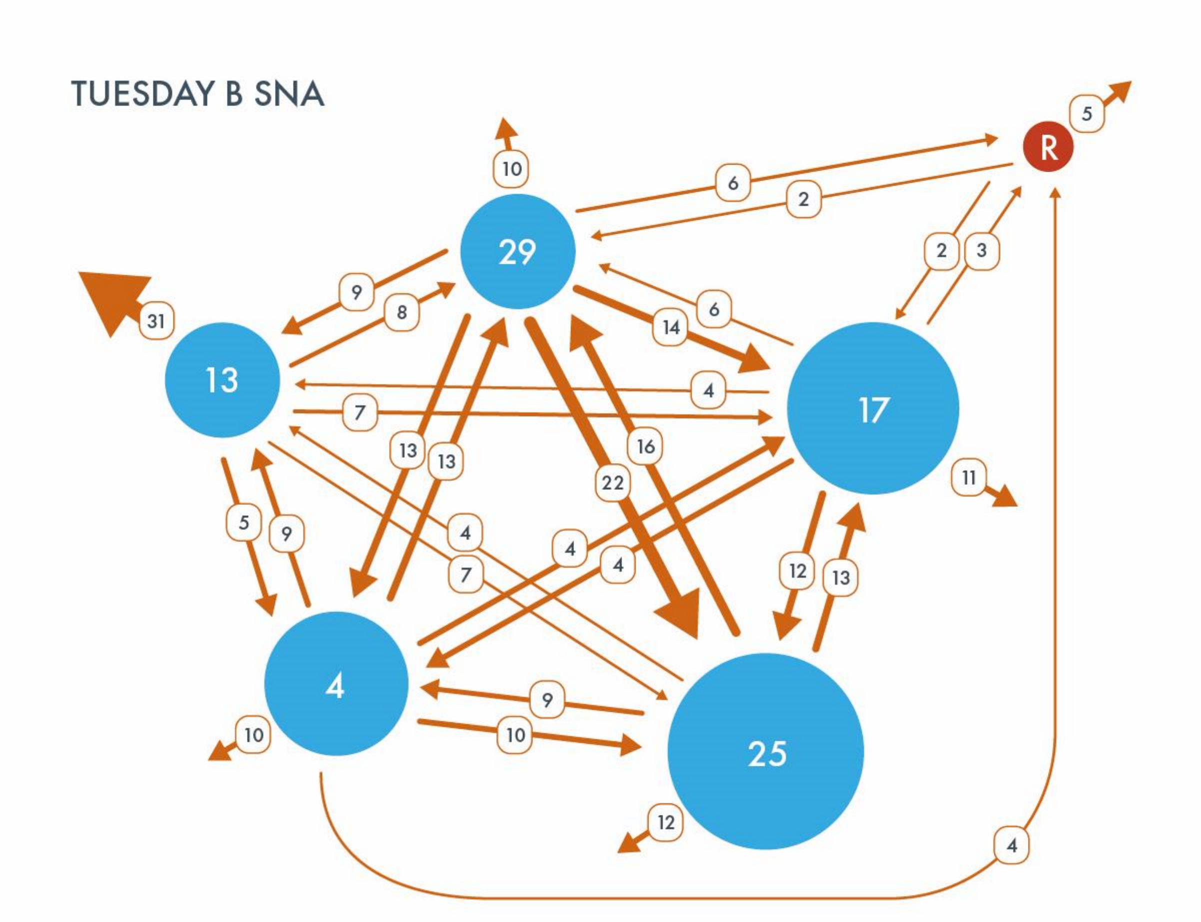


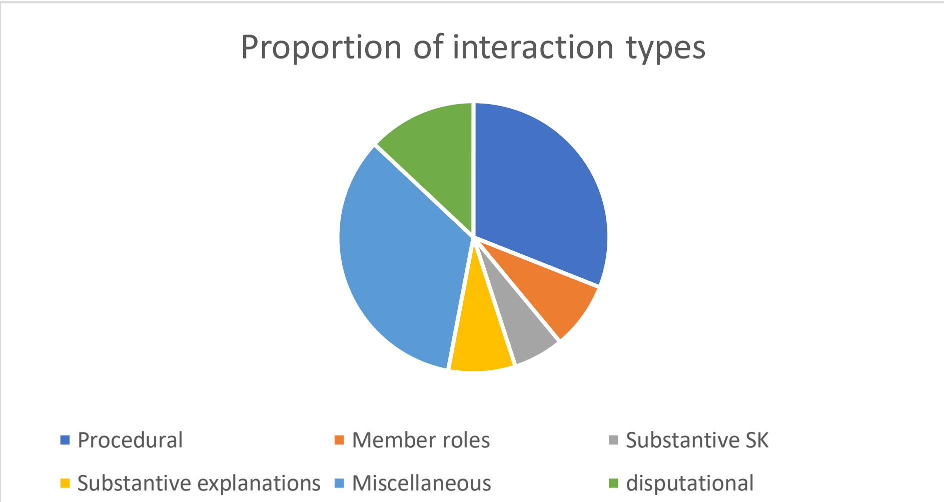
Figure 6.25 Sociograph of Tuesday B group work interactions. The red node (R) represents the researcher who briefly interacted with pupils 4, 25, 17 and 29 during the episode.

Pupil	In-degree	Out-degree	Net in-degree	Connectivity (*n=5*)	Presence adjustment	Significance adjustment	Influence ranking
25	51	54	**-3**	*n*=4	-	$\uparrow$	**1**
17	40	40	**0**	*n*=5	-	$\downarrow$	**2**
4	31	50	**-19**	*n*=4	-	-	**3**
29	45	74	**-29**	*n*=5	-	-	**4**
13	26	58	**-32**	*n*=4	-	-	**5**

Table 6.5 Factors determining relative nodal influence

This episode had higher than normal proportions of miscellaneous interactions and group conflict. These were more prominent in the second half of the episode and most of the incidents of learning were apparent in the first half. Pupil 25 was the most salient node in the system with a net in-degree of -3 and upward adjustment for the significance of his contributions. Whilst pupil 17’s net in-degree (0) and connectivity (5) appeared most influential, adjusting for significance lowered his overall influence ranking, indicative of observational evidence from the video that he followed pupil 25’s lead throughout. There are several noteworthy particularities evident in the sociograph data. Firstly, pupil 13 directed almost all his utterances towards the group in general and consequently received the least interactions back making him the least influential node (net in-degree -32). Most of these utterances were made whilst working on a laptop and without looking up from the laptop, thinking out loud. Though his connectivity (4) is in keeping with other members, purposefully directed interactions were few and it would be fair to speculate that little about the episode may have changed had he not been present. Second-least influential in this episode was pupil 29, who despite interacting the most frequently and being widely connected, had a significant net negative in-degree (-29). Pupil 29 talked a lot, and her interactions influenced the course of dialogue and action, however with one or two noteworthy exceptions most of her utterances were conflict-based. The picture is similar with pupil 4, who despite having a more favourable net in-degree (-19), was repeatedly engaged in conflict, mostly with pupil 29. Pupil 25 held the highest social and subject knowledge status in the group which explains why he became the principal hub through which interactions passed. The researcher (R) briefly interacted with the group approximately halfway through the episode.

6.6.2 Interaction type proportion data



31% of interactions were procedural

8% of interactions related to group member roles

6% of interactions related to substantive subject knowledge

8% of interactions were explanations about the substantive topic

13% of interactions were social conflict

34% of interactions were miscellaneous

86% of interactions (procedural, member roles, dispute and miscellaneous) did not directly relate to the substantive topic or task (constructing rocket wings). The remaining 14% were roughly evenly distributed between questions about and assertions of subject knowledge, explanations of processes, cause-effect links, or justifications of procedural decisions. All questions came from pupil 29 and all but one explanation came from pupil 25. Pupil 25's involvement in all seven critical learning incidents described below is consistent with the sociograph data showing that he was the most influential node in the system. The relatively high proportion (13%) of disputational interactions emerged between pupils 4 and 29 and had a mixed influence on the emergence of learning during the episode, as explained below. The focus of this conflict was member roles, though these utterances are recorded as conflict and designated as distinct from constructive dialogue about who would do what. Most of the disputes emerged towards the second half of the recorded episode, rendering this half of the episode less productive in terms of task and learning orientation. All of the critical learning incidents presented below occurred during the first half of the recording.

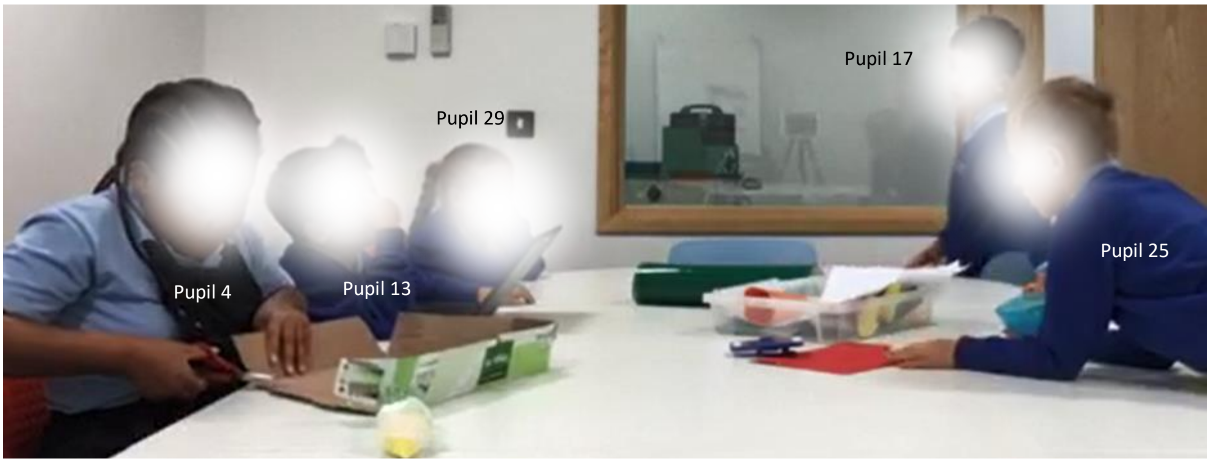


Figure 6.27 Still #1 of episode Tuesday B recording. Pupils 4, 13, 29, 17 and 25

6.6.3 Critical Learning Incidents

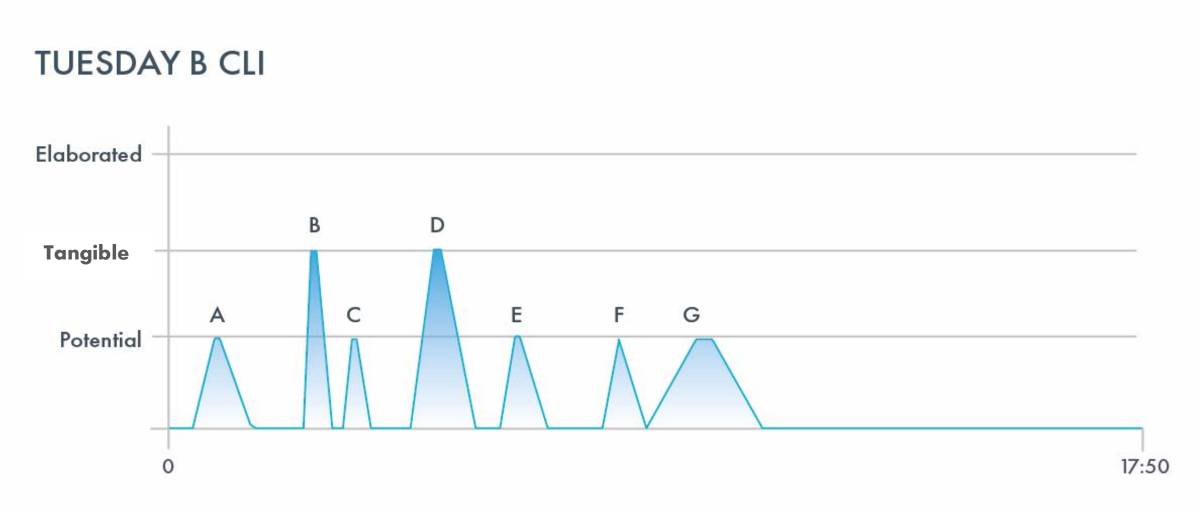


Figure 6.28 Critical learning incidents in group work video episode Tuesday B.

There were seven incidents judged as critical during this episode, three tangible and four potential. The almost constant talking over one another which characterised the episode resulted in little opportunity for elaborated interactions.

6.6.4 Critical Learning Incident Vignettes

Incident A (01:56) was a tangible example of one pupil learning from other pupils. Pupil 17 began to explain his idea for where they should position the wings to pupil 29. Pupil 25 interrupted and took over, sharing his idea. Whilst pupil 25 explained his plan to make and test elliptical (oval) and delta (triangular) styles, he demonstrated by positioning the sets of wings on the rocket. The interaction was as follows:

Pupil 25: Can I just tell you what I think?

Pupil 17: Yes (hands pupil 25 the rocket)

Pupil 25: So, the wings go from here (gestures to the top of the rocket) to here (gestures to the bottom).

Pupil 17: And then at the bottom there (points)

Pupil 25: And here (gestures) is where the elliptical wings go.

Pupil 29: What's elliptical wings?

Pupil 25: The circle shaped ones.

Pupil 29: Why do we need four though? Why we need four wings?

Pupil 17: To hold…to…because…the first wings there will go near the (nose) cone and the others make it very stable.

Whilst there is no tangible evidence that pupil 29 learned from this interaction, the potential for subject knowledge seeds to be planted about elliptical wings and stability was evident. Later, in incident C (05:00) pupil 29 asked why they are making two sets of wings (elliptical and delta). Pupil 25 explained that each pair of wings plays a different role.

Although brief, there is evidence of a learning opportunity for pupils 29, 25 and 17. Pupil 29 potentially gained insight about why two sets of wings might be beneficial (although the explanation did not convey much) and pupil 17 may have benefitted from attempting to articulate his explanation. The hesitation at the beginning of pupil 17's response suggests that the question forced him to consider his explanation before articulating it. The lack of detail in his response also indicates that his understanding of the benefits of having both sets of wings is also incomplete. Pupil 29's question was not planned, but its emergence (as a consequence of a lack of knowledge) prompted potential learning for her, for pupil 25 and for pupil 17.

Later the same afternoon (Tuesday) pupil 17 added a 'knowledge' MoL to the learning wall which read

> "*We were on the carpet and the next slide (of the teacher's presentation) showed the best wings and I was surprised that the best was like an oval".*

This MoL demonstrates that pupil 17's understanding of optimal wing shapes remained partial after the design activity. This was evident in his incomplete explanation of wing functions to pupil 29 (above) and reveals an incremental characteristic of learning.

After testing their prototype the following day (Wednesday), pupil 17 added a 'knowledge' MoL post-it to the learning wall which read

> "*I know that the simple delta (wing) is very useful for cutting through the air. I learned this while experimenting".*

On this evidence it appears that pupil 17's knowledge of different wings and their function grew after practical experimentation and first-hand observation. It is interesting that whilst not entirely contradicting the knowledge expressed in his MoL from the previous day (that oval shaped wings were best), this MoL does imply a different conclusion. This illustrates not only that understanding has incremental characteristics, but also that it is a function of multiple sources, in this case practical action (making wings), being taught or given information and hands-on experimentation. A subsequent interview with pupil 17 illustrated how he assimilated facts he was taught about the benefits of elliptical wings with his prior assumption that delta wings would be most effective:

Researcher: …..Right then, let's talk about this one here (pupil 17's MoL). Do you want to read that out to me?

Pupil 17: Okay. We were on the carpet and the next slide showed the best wings and I was surprised that the best was like an oval.

Researcher: Okay.

Pupil 17: I learnt this from the active panel (on the white board)

Researcher: Yes, you did. Right, so tell me why that surprised you?

Pupil 17: Um because I was originally thinking that the best wings would be like in a triangle shape.

Researcher: Okay, and what made you think that?

Pupil 17: Because the air could just cut around them.

Researcher: Okay. Do you have any idea why the oval shaped ones might actually be best? Can you remember?

Pupil 17: Because at the top it's like that, it's like circular, so I guess what would happen is the air would just travel round it.

Researcher: Okay, that's really interesting, yeah. When you were in that moment, describe to me what was happening around you during that moment. You were in the home zone?

Pupil 17: And (teacher's name) was teaching us.

Researcher: Right, okay. Was everyone else there as well?

Pupil 17: Everybody was at school that day in our class.

Researcher: Okay. Would you say (teacher's name) taught you that fact? How did you discover it? Was it because (teacher's name) told you?

Pupil 17: Um it was because it basically showed all the best wings and I just saw the best for aerodynamic stuff is an oval!

Researcher: Oh okay, that's interesting. When you say that surprised you, that's because you didn't predict that, did you?

Pupil 17: No, I didn't.

Researcher: You predicted something else. Okay. So (teacher's name) helped you learn that.

Pupil 17: Yeah.

Researcher: And the information on the board, on the active panel, helped you learn that as well. How are you going to use that bit of knowledge?

Pupil 17: Well, when we were in here with my whole group *(Group work episode Tuesday (b))*, we made those wings, those oval shaped wings, and we've tested them out.

Researcher: Okay, oh right!

Pupil 17: Surprisingly the ones I thought would work the best (triangular delta wings) did work the best.

In this interview sequence pupil 17 described his surprise when confronted with information contradicting his working hypothesis; as well as how this information influenced decisions about which type of wings to make and test (in fact they made both delta and elliptical and put them on both on the rocket). Pupil 17's responses show how different sources, structured and unstructured, shaped his (and his group's) thinking and decision-making about their rocket design.

Learning incident B (Figure 6.28, 04:03) was a more tangible example of learning. Pupil 25 held the rocket, moved it through the air and commented that because the nose cone was off-centre it was unlikely to fly straight. Pupil 29 agreed. Pupil 25 then began removing the nose cone to straighten it. This topic re-emerged at 06:03 when pupil 25 discussed it with pupil 17. Noticeable in this short sequence is Pupil 25's implicit causal understanding of the movement of objects through air and the potential for learning on the part of pupil 29.

Figure 6.29 Still #2 of Tuesday B recording. Pupil 25 explains his emerging theory about the effect of the off-centre nose cone to pupil 29.

Pupil 25: (moving rocket through the air) if we have it this way round (nose pointing upwards) it'll probably go like this (flies it upwards) and if we have it this way (nose pointing downwards) it'll probably….

Pupil 29: …go down.

Pupil 25: (motions rocket downwards). If we could just shift it a bit (fiddling with the nose) it'd probably work much better.

Pupil 17 re-joined the group, having briefly exited, and began a new conversation.

Although evidence of tangible learning about rocket flight is evident in this short extract, the lack of any sustained or elaborated explanation inhibits a designation of ‘elaborated’ learning. There was a shared understanding apparent between pupils 29 and 25, though pupil 25 appeared to have a more secure understanding based on the actions, body language and lead he took in the exchange. Whilst pupil 25’s understanding was on show, it could be speculated that pupil 29 also benefitted from his explanation and its accompanying visual demonstration and that this ‘teaching’ accounts for her completing his sentence (above).

In incident D (Figure 6.28, 06:03), having adjusted the position and shape of the nosecone, pupil 25 explained and demonstrated his concern about its off-centre position to pupil 17 and asked if it now looked better. They rehearsed moving the rocket through the air along possible pathways. Pupil 29 joined in and pupil 25 suggested they alter the shape of the nose cone more. Pupil 29 performed a test-throw of the rocket into some space, adding that if they put wings on it too it would be more stable. In this sequence there is tangible hypothesis, prediction and explanation on the part of pupils 25 and 17, but more significantly, pupil 29 demonstrates her learning from incident C (a few minutes earlier) about the function of wings in producing stability. In the case of incidents B and D, learning interactions were prompted by prior error (the nose cone being poorly formed and attached). The topic in both these instances (nose cone) was also not the intended focus of the group activity, illustrating how learning realisations are not always congruous in time and place with the task in hand.

During incident E (08:14) I had joined the group (R) asking which wing designs they were using. Pupil 17 explained their plan to use two sets of wings, delta and elliptical. This was potentially a ‘tangible’ or ‘elaborated’ learning incident, however the other four group members begin arguing at this point and the dialogue between myself and pupil 17 was inaudible.

During incident F (11:51) pupil 25 drew wing outlines on a piece of card and pupil 17 suggested that the outline was too big. Pupil 25 responded by placing the bottle rocket on top of the card and positioning it so that the drawn outline was in position to demonstrate that the wing size was appropriate. Evident in this incident are testing, observation, searching for proof and practical problem solving. Pupil 17 observed and listened to pupil 25's response but did not reply. It is possible that he will have learned from pupil 25's demonstration. It is also possible that, having had his own judgement challenged and demonstrated to be incorrect in this instance, pupil 17's assessment of his own judgement will have been influenced.

The final critical incident in the episode (G) occurred at 12:03 and appeared to be a direct consequence of pupils 4 and 29 arguing. Their dispute over who should cut out the elliptical wings appeared to prompt the most productive, task-orientated period in the episode. Whilst pupils 4 and 29 argued, pupils 13, 25 and 17 put their heads down, avoided getting involved and continued their respective tasks in silence. More seemed to be achieved in this sequence of approximately one minute than in any other period in the episode, and whilst there is no tangible evidence of learning here, it is noteworthy that conflict between two members appeared to result in increased task-orientation and productivity from the others.

6.6.5 Antecedents of learning

Learning in these incidents, potential and tangible appear to have certain shared antecedents. Firstly, each incident can be said to have emerged, rather than have been planned for. In some cases (C and D) learning which emerged concerned a topic which was not in fact the subject of the current activity. Incidents A, C and D illustrate how opportunities for learning can arise out of gaps in knowledge and misunderstandings in bottom-up, locally organised group interactions. Learning in these instances is also partly a consequence of group diversity. Gaps in knowledge and understanding among some members drew explanation and reasoning from other members, from which both parties have potential to benefit. Incident G arose out of conflict, illustrating that whilst conflict is undesirable, from a systems-thinking perspective, it can prompt conditions for potential learning.

Also consistent across these incidents is the notable lack of extended or elaborated evidence of learning. This also appears to be a system characteristic during decentralised group interactions. It is possible that any emergent learning gains are counter-balanced by missed opportunities for elaborated explanation and reasoning which a top-down structure might have facilitated. This relationship was noted repeatedly in the researcher's field log. The following extracts illustrate this.

Tuesday 18th June (Afternoon)

> *'The children are not used to independent activity. Monday morning showed this to an extent. Factors like self-control, peer cooperation, planning etc. did obstruct learning to an extent'*

Thursday 20th June (morning – decentralised and distributed structures)

> *'Relationship between activity, autonomy, cooperation and learning. The more autonomous the learning and activity, the more social relationships and degrees of peer cooperation mediate learning'.*

The first observation was apparent from day one and remained largely unchanged throughout the week. The second point, that greater pupil autonomy increased the influence of social co-operation on learning, is pertinent to this episode. High levels of conflict had different effects on learning, one being that elaborated explanations, discussion or reasoning was obstructed.

Wednesday 19th June (afternoon – decentralised and distributed structures)

> *'The most significant variables not within the teacher's control seem to be the 'social scene' (including cooperation skills, selfless/ish tendencies, commitment to getting one's own way- which appear to have a strong mediating influence on achievement of tasks and learning focus)'.*

This extract captures a useful reminder that pupils are individuals, pursuing individual, as well as collective, goals. Observations of the class operating in decentralised and distributed structures suggest that social/emotional maturity and the corresponding development of co-operation skills can be significant determinants of success in achieving learning goals.

Social dynamics were a significant influence in this episode. Firstly, the density of interruption which prevented any elaborated articulations was high. Secondly, as with all the decentralised episodes, social status shaped the direction of interactions and influenced what emerged. As evidenced in the sociograph data, pupil 25 was salient in social status and was the most significant interactive hub. Video data also shows clearly that pupil 25 drove productivity within the group, had most ideas about what to do and was frequently consulted by the other group members (except pupil 13) about what they should do. Pupil 25's assumption of this leadership role was partly explained in a later interview in which he explained his enthusiasm for science:

Researcher: Okay, so have you enjoyed what we've done yesterday and today with the rockets?

Pupil 25: Yeah.

Researcher: What things have you liked in particular?

Pupil 25: Well, I liked shooting the rockets and I liked building like pieces of it because like when I'm older I want to be a scientist and know stuff and invent stuff.

Researcher: Do you? Oh wow, so this is right up your street then? That's nice.

Pupil 25: And I also have a periodic table in my bedroom and my favourite ones are element (a), element (b) and element (c).

Researcher: Oh wow. Okay, why those ones?

Pupil 25: Because each one is the beginning two letters of my family's name, because XX is the beginning two letters of my name and X is element (a).

Researcher: That's right.

Pupil 25: XX is the beginning two letters of my mum's name and silver is XX, and XX is element (c) and there's the two first letters of my sister's name.

Pupil 25's subsequent explanation of how he learns most effectively goes some way to explain the role he assumed in explaining and demonstrating to other group members:

Researcher: [laughs] See if you can complete this sentence: I tend to learn best when…

Pupil 25: I do things.

Researcher: Oh really? Tell me about that.

Pupil 25: Like if I try and ride a bike, for example, let's say I didn't know how to ride one, if someone says you have to pedal the pedals and turn the handles, it's not that clear because someone might be pedalling with their hands instead of with their feet, for example, and putting their head on the bum rest or something.

Researcher: Okay.

Pupil 25: But like if I do something I can be told if it's incorrect or correct and then I can do it better the second time.

Researcher: Right, so you like to experience the thing that you're learning to do or learning about?

Pupil 25: Yeah.

6.7 Summary and CAS analysis

Several CAS characteristics are evident in this narrative. Firstly, autonomy, impulsivity, self-interest prompted pupils into self-organise into patterns of social negotiation and conflict. Equilibrium was perturbed regularly, but not always in the interest of learning. Pupils competed for status, negotiating (clumsily at times) roles, relationships and identities. The absence of critical learning incidents when conflict peaked was notable and raises questions about where the border lies between *edge of* and *actual* chaos states, and if a space exists between sources of coherence and disruption which is fertile for emergent learning. According to complexity thinking, edge of chaos states can be productive cites for system change and emergence, however in goal-directed activities such as classroom learning, autonomy without structure appears to inhibit intended goals. There were incidents in which learning emerged unplanned, from group interaction. As in previous narratives, learning incidents and subsequent learning evident in pupil interviews and MoLs appeared to have multiple sources from different times and contexts which is indicative of the non-linear, networked causality of learning. Information did not travel from teacher to pupils, but emerged gradually across time, locations, activities and interactions. This is also evident in instances where learning emerged about topics only indirectly related to the task at hand. The pupils affected one another cognitively, socially and emotionally. Knowledge and hypotheses from individuals fed back into the group, influencing decisions. In this episode learning incidents were linked and give an interesting illustration of how knowledge and understanding build unevenly over time. Similar to previous narratives, asymmetries of knowledge and understanding between group members (system diversity) appeared to be a driver of change.

6.8 Summary of findings and discussion points

Key findings arising from analysis of these three learning narratives are as follows:

1. Salient individuals exert considerable influence on collective dynamics and the emergence of learning. This was evident in all three narratives, where influential pupils were lynchpins within most learning incidents. Salience derived from social status appeared to override knowledge-based salience where these were held by different students, though there is evidence that even a disruptive influence of a pupil high in social status but low in conscientiousness can occasion learning.

2. Social conflict and other apparently off-task interactions can prompt learning to emerge, though not consistently. There are multiple examples across the three narratives of potential or tangible incidents of learning, or conditions for learning, emerging unexpectedly out of uncooperativeness, silliness or other ‘inappropriate’ behaviours. Evidence suggests that behaviours generally thought of as undesirable can invoke learning, though inconsistently and not in elaborated forms. Disruption had some negative influences on learning, but also occasioned opportunities which might otherwise not have arisen. It was not the case that where there was more conflict there was less learning evident, though learning which emerged out of conflict was less likely to be curriculum orientated. The picture was mixed.

3. Emergent learning appears to be limited to ‘potential’ and ‘tangible’ forms. All instances of ‘elaborated’ learning in the three narratives occurred with an adult present and engaged. This raises interesting questions about the limitations of emergent learning and whether un-scaffolded, local organisation can lead to elaborated learning. Critical learning incident data showing that when adult engagement increases, pupil autonomy and emergent learning decreases, suggests that top-down and bottom-up organisation of learning cannot easily coexist, since one will naturally override the other.

4. Internal diversity is a driver of emergent learning Scrutiny of learning incident data and analysis of video episodes suggests that diversity, particularly of knowledge and understanding and personality traits, can be instrumental in the emergence of learning. Deficits in knowledge or understanding are exposed by group interaction. The collision of ideas drew out reasoning. Those with more secure knowledge tended to share it. Personality traits, including extraversion, introversion, openness and conscientiousness interact with one another in networked, non-linear ways and so influence group dynamics and activity. System composition is therefore influential on what learning emerges.

5. Decentralised learning structures have several CAS-like characteristics, though not consistently. Scrutinising the data through the lens of CAS-framed interrogative questions revealed that learning, particularly in a decentralised organisational structure, has certain CAS characteristics. Pupil autonomy combined with effects of internal diversity created states fit for learning to emerge unexpectedly. Individual and group learning were not always linear. Time, space and location acted more like variables than constants in learning. Edge of chaos states were evident, though resulting system changes were not always in the interest of productivity or learning goals. Feedback loops facilitated level jumping, where change at individual level transferred to whole class level. However, these features were occasional, not the norm. These findings will form the basis of discussions in Chapter Seven.

7.0 Discussion

7.1 Introduction

This chapter places the findings from Chapter Six in the context of the research aims, a complex systems interpretation of learning through decentralised classroom interaction. It draws on the CAS framing presented in Chapter Three, along with literature, to distil the contributions this research makes to the field, delving into the meaning and relevance of the findings. The discussion is structured around the key findings presented at the end of Chapter Six, which are discussed with reference to features of CASs and what they reveal about learning as an emergent phenomenon.

As in Chapter Two, this chapter draws on literature from two distinct epistemological positions. Firstly, the pragmatism of 'what works', where the objective is to uncover how teaching can produce curriculum attainment. As discussed in Chapters Two and Three, I have conceptualised 'what works' broadly to include not only a narrow range of politically motivated and prescriptive policy recommendations for schools and teachers, but also conclusions arising from any classroom-based research predicated on the assumption that learning is a function of teaching input, which is most classroom research. I have termed the latter a 'soft what works' approach. Secondly, and in contrast to 'what works', the heuristic of complexity thinking, which thus far has largely concerned itself with describing classrooms in terms of their complex behaviours. Whilst there are overlaps between these two, they do not share the same philosophical, epistemological or axiological starting points (see Chapter Three). It was not my intention in this thesis to attempt to resolve tensions between these approaches and therefore literature from both camps is used side by side in this discussion. Counterpoint between 'what works' and complexity is pertinent to each of the findings, however it surfaces predominantly in section 7.2.5.

The purpose of this discussion chapter is to contextualise responses to the research questions presented in Chapter One:

RQ1: To what extent can learning be said to have ‘emerged’ within small group classroom activity?

RQ2: What are the characteristics and value of ‘emergent’ learning?

RQ3: What conditions encourage ‘emergent’ learning?

RQ4: How useful is a CAS framing for analysing primary classroom small group learning?

As set out in Chapter Five, for the purposes of this study I have defined ‘emergent learning’ as: **Learning, potential, tangible or elaborated, which materialises through autonomous interaction between pupils, resources and environment, rather than directly from top-down teacher control.** An important note about nomenclature; the term emergent learning here refers to learning which according to scrutiny of the data, appears to have materialised from the bottom up. It does not refer to as yet undeveloped learning, to avoid confusion, this is referred to using the term from the data analysis, ‘potential’ learning. Later in the chapter I also use the terms ‘soon to be’ learning and ‘becoming’ learning to refer to learning which is tentative and not yet fully articulated. However, where I use the term emergent learning it always refers to how it occurred (it emerged), rather than the completeness of the learning itself.

Findings from Chapter Six are organised into two broad sections, firstly concerning the roles which internal system diversity plays in the emergence of learning and secondly, the nature of emergent learning.

7.2 Discussion of key findings

7.2.1 Internal system diversity

7.2.1.1 Internal diversity is a driver of emergent learning.

The ‘what works’ literature notes specific problems associated with status asymmetries among pupils working together (see section 7.2.1.3), researchers of interactive group learning are enthusiastic about other forms of internal diversity. As previously highlighted, Baines *et al.,* (2006) suggest that for interactive group work to be effective (in terms of meeting curriculum outcomes), it should be planned and organised carefully. Bennett and Cass (1989) point to clear links between group composition and group outcomes and advise careful attention to the composition of groups for collaboration. Whilst heterogeneity is welcomed at whole class level, careful attention to group composition tends to mean implementing measures to minimise its effects at small group level. This is seen in common practice of ‘ability’ grouping which views asymmetries as problems to be solved, much like the approach to social dominance discussed in section 7.2.1.2 below, and seeks to homogenise pupil interactions (Wilkinson and Fung, 2002). If internal diversity can be minimised then the likelihood of pupils dominating, withdrawing or freeloading are also minimised (Veldman *et al.,* 2020; Slavin, Hurley and Chamberlain, 2003). However, advocates for internal diversity suggest that ‘mixed ability’ groupings are beneficial (Wilkinson and Fung, 2002). They generate the widest range of viewpoints and ideas (Cremin and Arthur, 2014), promote relational equity, engender responsibility towards lower attaining peers, and improved achievement (Boaler, 2006; 2008). There is also a presumption that higher attaining pupils will assist their lower attaining peers (Webb, Baxter and Thompson, 1997 – a proposition which often goes unrealised in my experience) and that learning gains of higher attaining pupils are unaffected in the process.

From a complexity thinking perspective, diversity is more broadly conceived however, referring to the myriad differences pupils bring to interactions which introduce asymmetries, moving collectives away from equilibrium. Internal group diversity in this sense reveals itself well beyond immutable identity markers such as sex or race, in personalities, cognition, personal histories, family background, personal interest, motivation levels, relationships and so on, down to the neurological level. It also includes elements of tasks and features of the environment. According to Davis and Sumara (2006, p.138) such difference 'defines the range and contours of possible responses' within group interactions. For Arrow, Mcgrath and Berdahl (2000), heterogeneity in small groups is essential to ensure that members change one another. As discussed in Chapter Two, diversity includes any factors which introduce counterpoint within the system, including mental and emotional states, peer relationships or pupil subcultures (such as social status). The groups in this study were deliberately constructed by the teacher to be 'mixed ability', for the reasons described above. However, internal diversity was broader than is captured by notions of ability, and more so than could be isolated by my observations in this study. Observable differences within the pupil groupings included sex, experience, personal histories, SES, family background, ethnicity, religion, extroversion, openness, competitiveness, social status, cognitive ability, subject knowledge and motivation levels, among others. Differences in environment (including the presence of the teacher and researcher), resources and task elements also observably influenced proceedings. Each of these points of diversity (and many unobservable others) shaped the interactions evident in the data. This resonates with Clark and Yinger's assertion that every classroom situation is the result of 'uniquely configured events' (1987, p.18), and Mennin's (2007) point that such heterogeneity is the reason group members adapt one another. According to Davis and Sumara (2006), numerous diversities exist in human social groupings irrespective of how homogenously conceived. They argue that diversity should be assumed.

The data yielded some useful examples of learning being provoked by diversity. For example, in narrative one where collisions between social, cognitive and personality diversities occasioned unpredictable actions and reactions among pupils; or narrative two where justification, reasoning and explanation all emerged through differences of opinion and disagreement. In narrative three, gaps in knowledge and understanding among some members drew explanation and reasoning from others. It seems reasonable to assume that had all members known the same things to the same level and shared the same personality traits such explanatory interactions would not have surfaced. A benefit of complex systems thinking in this study was that it drew my focus away from merely *what* occurred, towards considering *how* and *why*. In terms of diversity, the factors which most clearly steered group dynamics and established conditions for learning to emerge were cognitive/knowledge-based, pupil subcultures (friendships, social status), viewpoints/perspectives and personality-based (conscientiousness, assertiveness, competitiveness, introversion/extroversion). Behind each of these factors lies a range of less visible (and therefore less directly attributable) networked causalities crossing nested levels, including from the neurological and the home or community. These are presumed to be influential but were beyond the scope of this study to observe.

Multiple complexity framed studies and discussions about classroom learning (Hardman, 2010, 2015; Burns and Knox, 2011; Sullivan, 2009; Newell, 2008; Dalke, *et al.*, 2007; Davis and Sumara, 2006; Davis and Simmt, 2003; 2006) highlight that given sufficient internal diversity and pupil interconnectedness, emergence can be expected. Hardman (2015) for example, emphasises the influence of personal histories and contributions of neurodiversity, down to the level of synaptic architecture. Burns and Knox (2011) emphasise the influence of the classroom environment, including wall displays and available resources and pupil relationships. Sullivan (2009) discusses how a range of diversities influence the classroom system, including opinions, experiences and teacher actions. A useful question to ask about the small range of observable diverse pupil characteristics in this study, is whether and to what extent it is fruitful for teachers to factor them into planning for interactive group work, and how feasible this might be? Davis and Sumara (2006) point out that diversities can be suppressed in teaching and learning contexts, thereby reducing the potential for randomness and innovation. However, as seen in the data, in some instances randomness and innovation were integral to emergence. Whether the practices of flattening out asymmetries among pupils are sympathetic or antithetic to learning will depend to a large extent on how learning is framed. As noted in Chapter Two, studies from psychology (Piaget, 1952), education (Mercer and Littleton, 2007; Perret-Claremont, 1993; Doise and Mugny, 1984; Mugny, Perret-Clermont and Doise, 1981; Perret-Claremont, 1980) and complexity (Newell, 2008; Davis and Sumara, 2006) converge on the notion that for learning to occur in social collaboration ideas must collide. A central observation about agent interaction within complex systems is that not all interactions produce self-organised emergence. If a classroom can be called a complex adaptive system (a proposition still up for debate – see Knight, *in press*), then interactions between pupils' ideas, hunches, talents, status, personalities, motivations and so on, will give rise to learning which transcends the sum of individual pupil knowledge (more on this in section 7.2.2). It seems logical, and is confirmed to some extent in the data, that diversity would be a significant driver of this. To borrow from Piaget's (1985) notion of cognitive conflict, diversity creates disequilibrium(s), not only in individuals but also within collectives, which are resolved through the collision of diversities.

For diversity to resolve into patterns of coherent emergence and avoid spilling over into chaos however, Davis and Sumara (2006) point out that redundancy is a necessary counterbalance. Redundancy in this sense refers to surpluses of elements within a system which enable agents to compensate for one another's weaknesses or skill shortages. Whilst pupils in a classroom or small group might be diverse in many ways, they also share much in common and overlap in many ways. Absolute diversity would make interaction impossible. Meaningful interactions are facilitated by what members have in common, knowledge, experiences and competencies they share. Similarly, absolute redundancy would negate any counterpoint from which the system and its members could innovate, create and change. In a complex system, diversity and redundancy therefore are phenomenon which help the system maintain balance between disruption and coherence. Redundancy was evident across all three narratives, illustrated by pupils' overlaps in knowledge or understandings. The data in this study points to diversity occasioning 'potential' learning, though in many instances this was a long way from the sort of elaborated visible curriculum learning pursued in 'what works' research. In some instances, this was due to an overload of redundancy whereby counterpoints between pupils were insufficient to inject innovation and little by way of learning occurred. In addition to provoking incidents of learning, diversity also produced dynamics which prevented it, often in the form of conflict. This is discussed in section 7.2.1.3.

7.2.1.2 Salient individuals exert considerable influence on collective dynamics and the emergence of learning.

Evident in all three learning narratives were ways in which salient individuals affected the course and outcomes of interactions. 'Salience', in this context, is an observation about the impact individuals exerted in the group work episodes, it is not a statement of fact or a permanent designation. Individuals who were salient in one episode may not have been in another. Salience was judged based on my reading and interpretation of each episode, along with my extensive experience of the primary classroom. Salient individuals tended to dictate the form and direction which interactions took; less influential individuals tended to follow their lead. Salience showed itself primarily as social status, superior knowledge or conscientiousness, each of which influenced interactive episodes differently, but also overlapped. For example, knowledge salience enabled pupil 12 to lead using his subject knowledge and conceptual understanding. Individuals with socially orientated salience, such as pupils 16 and 20, derived salience from their apparent social standing within the group. Conscientiousness-related salience, as in pupils 12, 19 and 29, produced influence from determination to stay on-task and meet group objectives. Conscientiousness appeared only to produce salience when combined with sufficient social standing or personal determination. This was evident with both pupils 19 and 29 who were salient to group proceedings in later episodes, having influenced little in earlier ones. As such, salience seemed to be mediated by pre-requisites, including personality.

The ’what works’ research literature concerning interactive group work tends to treat asymmetries of contribution and socially dominant individuals as problems to be solved. Galton (1996) and Cohen (1994) for example, emphasise that co-operative (learning) groups must overcome problems of status among pupils. Cohen noted that high status pupils (defined by attainment, social class) are likely to dominate group activities which presents a challenge to the goal of every pupil meeting planned learning objectives. Several researchers (Galton and Hargreaves, 2009; London and Sessa, 2007; Cohen and Intilli, 1981) have noted that asymmetries in social or other forms of status can lead to dysfunctionality. Flattening out the social landscape so that all pupils enjoy equal status in interactive work (as with ability grouping) is seen as desirable for cooperation, equal contributions and achievement of learning outcomes. However, London and Sessa also point out that achieving this is extremely difficult. Various strategies have been suggested to prevent social dominance from taking hold in group work, all based around the principle that groups should be carefully planned and organised by teachers (Blatchford, *et al.,* 2006). These include, careful selection and composition of pupil groupings (Wilkinson and Fung, 2002), distributing high social status pupils across groups or grouping according to social status, teaching rules for group work (Jolliffe, 2012; Webb and Mastergeorge, 2003; Gillies, 2003) and assigning member roles.

Whilst it is understandable to conceive of social dominance as a problem teachers must solve, findings from this study suggest that asymmetries in social status can also give rise to learning opportunities. An example if this is seen in differences between episodes Monday A and B. These two episodes provide useful illustrations of the ways that social status can influence group interactions and indirectly influence productivity and learning. In the first episode (Monday A) the pupil with the highest social status (pupil 12) was also high in knowledge and conscientiousness and was therefore salient in the episode. Later however, when the same group was joined by pupils 20 and 26, the highest social status resided with the least conscientious pupil (pupil 20) and the dynamic shifted away from productivity towards conflict and less task relevant interactions. This shift, which pupil 12 found challenging to manage, also brought opportunities, however. For example, the disruptive influence of pupil 20 and the disagreements it sparked prompted other pupils (most notably pupils 12, 10 and 26) to engage in heated disagreement which at times took on characteristics of scientific argumentation, eliciting explanation, reasoning and justification which might otherwise have remained tacit. In addition, group members (including pupil 20) benefitted from pupil 12's attempts to re-assert himself and his knowledge. Pupil 20 in-part owes his learning to pupil 12's perseverance and determination not to be side-lined. This episode was full of 'dysfunctionality', and yet close inspection of the interactions and what resulted from them revealed that the potential for learning, was present. The data also contains instances in which pupils with high social status were pivotal to learning, either because they acted as hubs through which interactions flowed (e.g., pupil 25 in episode Tuesday B) or because their presence created tensions from which new decisions, directions or patterns of behaviour emerged (e.g., pupil 4 in episode Tuesday B).

Salience has more dimensions than just social status, however. In other episodes, conscientiousness and subject knowledge also enabled individuals to influence the direction of group activities and learning. In episode Monday A, pupil 12's salience arose predominantly because of his superior knowledge compared to pupils 10 and 24 and I would argue that in this instance the asymmetry actually motivated pupil 12 to take the lead and share what he knew. A hypothesis emerges that the group dynamic created conditions which elicited focus, leadership and commitment from pupil 12, from which the whole group benefitted. In this analysis, the asymmetry apparent in the group interactions may have facilitated the surfacing of learning which a more symmetrical group dynamic may not have. Episodes Monday C and Tuesday A (Learning Narrative 2) provide the clearest illustration of salience influencing group activity and learning despite the absence of social status. It is reasonable to speculate that had pupil 19's peers listened to him, rather than ignoring him, his idea to join two bottles might have gained traction within, but not beyond, his group. However, because his group ignored him, he sought an alternative outlet and was eventually given the opportunity to share it with the whole class. In this instance, the comparatively low social standing of a group member (and his determination to air his idea) resulted in wider dissemination of learning. This contrasts with the more common phenomenon of ideas remaining tacit when originating from pupils of lower social status. The decision to leave the group and seek out the teacher could be described as a bifurcation as it was unpredictable, disrupted the prevailing hierarchy of ideas within the network and prompted information to move across levels within the classroom system. Pupil 19's combination of subject knowledge and determination eventually enabled him to articulate an idea from which the whole group (and whole class) benefitted. In episode Tuesday A, pupil 15 exerted considerable influence on her group to remain on-task, despite her apparent low social status in an earlier episode. During episode Monday B pupil 12, who was high in subject knowledge but whose social status dipped after the arrival of pupil 20, still exerted considerable influence on the network. Based on these few episodes, it seems reasonable to argue that whilst social, knowledge and personality asymmetries between interacting pupils can create obstacles to learning, they also have the potential to be assets. Even in episodes where social dominance or status clashes between pupils were frequent, the potential for learning was still apparent, lending support to arguments from Alexander, Shallert and Reynolds (2009) that learning (of some sort at least) is inevitable. However, instances of elaborated learning were rare, suggesting that whilst pupils might learn something from such interactions, they may not learn what was intended (Biesta, 2009) and resultant learning may only be partial (points discussed further in section 7.2.2.1).

From a complex systems perspective, asymmetries in salience, whether social, knowledge or personality-based, are part of what gives a complex unity its vibrancy and gives rise to novelty. According to Davis and Sumara (2006) differences (diversity) and overlaps (redundancy) among interacting individuals bring balance between sources of creativity and stability. This theme and its implications are discussed in section 7.2.2.2. Similar to the way air molecules resolve imbalances in pressure or thermal energy to transfer through convection, salience appears to introduce both imbalances and the socially engendered necessity to resolve them. Salient individuals appear to skew system dynamics in ways which produce bottom-up emergence, as individuals act and react to one another. Adopting a complexity thinking lens, interrogating interactive episodes non-linearly and being sensitive to potential (or soon to be) learning, reveals that in some instances asymmetries in pupil status proved valuable.

My intention here is not to argue that group interactions should not be carefully planned for and managed by teachers, that group dynamics do not matter or that all or any learning emerging from interactive episodes should be considered equally useful. Though it is not possible to predict what might have happened had the groupings been different, all three narratives contained instances in which group outcomes fell short of expectations, time was wasted and learning opportunities missed. Clearly, school exists so that pupils learn something, not just anything (Biesta, 2009) and configuring interactive learning in the interest of curriculum aims is essential. However, the findings do support an argument that typical assumptions about negative impacts of status asymmetries should not obscure their potential benefits and that whilst teachers are well advised to plan the composition of pupil groups, planning for asymmetries may be as fruitful as planning to flatten them out.

7.2.1.3 Social conflict and other less desirable or apparently off-task interactions can prompt learning to emerge, though not consistently.

Social conflict was common to all three narratives. Although the two can overlap, this section differentiates between social conflict, in which pupils fall out with one another, and cognitive conflict, in which pupils challenge one another's thinking. Social conflict can arise out of cognitive conflict, and vice versa (e.g., episodes Monday B and Tuesday A), however in most instances the two remained distinct in the data, therefore the focus of this section will be on social conflict alone. As with asymmetries discussed in previous sections, conflict among pupils is treated in the 'what works' literature as a cause, or evidence, of dysfunctionality.

A number of researchers (Rosenshine, 2015; London and Sessa, 2007; Mercer and Littleton, 2007; Barnes and Todd, 1977) have highlighted that pupil collaboration is rarely productive. A chief explanation for this is the influence of social conflict, which is seen as working against productivity and learning (Galton and Hargreaves, 2009) and solutions invariably require teacher interventions, either by coaching co-operative skills (Joliffe, 2012; Baines, Blatchford and Chowne, 2007), structuring activity with rules (Webb and Mastergeorge, 2003; Gillies, 2003) and member roles (Leung and Lewkowicz, 2013) or a combination of these. It is little surprise that nowhere in the literature is there any support for the idea that social conflict might also support learning in unexpected ways. Engendering cooperation, tolerance and kindness among pupils is central to the aims of schooling and there is no question that social conflict can be an obstacle to learning. However, the data suggests, albeit tentatively, that learning (or potential for learning) can emerge from it indirectly. This was evident in episode Monday B from narrative 1 and episode Tuesday B from narrative 3 where in both cases arguments about turn-taking, member roles or reactions to members' speech or actions injected unpredicted opportunities, resulting in new behaviours, decisions, or resolutions, some of which invited learning.

My intention here is not to advocate for social conflict, or champion havoc as grist to the mill of learning. Whilst reviewing footage video episode data, I reacted as any teacher might by presuming that the emergence of conflict would signal the cessation of learning; that the two could not coexist. This presumption proved correct in episode Tuesday B where constant interruptions inhibited elaborated interactions. However, by adopting a CAS lens and managing to stop thinking linearly as a teacher (a well-established habit in my case) and thinking non-linearly as a complexivist researcher, I did notice that conditions for learning emerged from some of these confrontations. In episode Monday episode B this was seen in the disruptive influence of pupil 20 whose assertiveness in taking control of the rocket launcher pump and the metre ruler forced other group members into different roles and elicited demonstrations and explanations from pupil 12. In the same episode, a constructive disagreement about which angle to set the launcher spilled over into an argument. Although the tone was confrontational and pupils were clearly jostling for position, all group members benefitted from this incident playing out. There is sufficient evidence to infer from this that conflict occasioned learning, though it is not possible to compare its quality or significance with learning which may have emerged had the disagreement been calmer. In episode Tuesday B an ongoing argument between pupils 4 and 29 caused the other pupils to attend to their tasks in what became the most productive period of the episode. My interpretation of these instances is that observable benefits emerging out of social conflict did not just survive the conflict but were occasioned by it. These were not circumstances which would have happened anyway, but which happened because of the ways pupils influenced one another through their interactions. Although only two instances across the three narratives, they illustrate how a prominent characteristic of complex systems, non-linearity, can arise from social conflict as pupils' actions and reactions feedback into one another. Doll (1989) noted that emergence tends to occur when there is difficulty to overcome, prompting some form of internal system reorganisation. According to Davis and Simmt (2003) it is this network of mutual self-influence between agents, environment and classroom climate, and the resulting randomness, which opens the door to novel moments of teaching and learning.

The question is, how might teachers use this knowledge to respond to the inevitability of social conflict between pupils. Understanding that whilst excessive social conflict is likely to have a net negative impact on curriculum learning, low level or occasional conflict can introduce novelty could lead teachers to re-evaluate their instincts to quash it immediately and instead to pause, observe and assess. If there are potential benefits in allowing conflict to play out, enabling pupils to find their own resolutions, this may lead teachers to re-assess when and how they intervene. Judging the line between tolerable and intolerable degrees of social conflict or noticing signs of potential benefits is unlikely to be easy, however the data tentatively implies there may be payoffs for teachers brave enough to try. The 'edge of chaos' (Davis and Sumara, 2006) will always be a double-edged sword, inviting innovation but also courting havoc. Semetsky (2005) acknowledges that radical visions of open and unrestrained classroom systems, whilst opening doors to possibility, might also be counterproductive. Accepting that interactive learning is by nature open and generative Biesta (2009) has argued in favour of enabling constraints which reduce complexity and unpredictability, but warns that these can be reduced too far, beyond a point where novelty, originality and innovation are unlikely to occur. He locates this point approximately where pupil autonomy, initiative and responsibility become unfeasible. A useful question for teachers therefore might be, how can I implement limits on interactive learning which enable, rather than dampen, novelty? As a teacher, I tended to run my classrooms with low tolerance for conflict, intervening swiftly where it occurred and implementing structures to constrain, rather than enable it. Reflecting on the data and its implications has given me pause for thought about the possible opportunities for novelty, innovation and new directions in learning which may have passed unrealised in my classrooms over the years. <u>Knowledge</u> that useful directions *can* emerge from social conflict, <u>situational sensitivity</u> to evaluate individual circumstances and <u>confidence</u> to match appropriate interventions (if intervening at all) are important for teachers wishing to capitalise on this finding.

Also evident in episodes of conflict was pupils jostling for or establishing status positions, resolving simmering disagreements, punctuating periods of concentration and establishing or shifting relationships. To the 'what works' eye such dynamics appear counter-productive and unlikely to encourage things to 'work'. However, a complex systems lens highlights the contributions such dynamics may make to emergent, or 'soon-to-be' learning. Such dynamics rarely play out overtly in centralised classroom configurations but are common in decentralised group work contexts. The predominant organising principle in the case study classroom was decentralised, meaning that table groups largely worked without the supervising presence of the teacher. This distance from the authoritative presence and the autonomy it allowed facilitated much of the social conflict, which raises questions about judgements of teacher-pupil proximity and the opportunities which may be gained or lost in the process. Close teacher proximity is likely to maintain social cohesion, task focus and productivity. However, in sustaining equilibrium and preserving group unity it may also forestall bifurcations through which the learning might take novel directions, as illustrated by the examples of pupil 20 in narrative 1, pupil 19 in narrative 2 and pupils 4 and 29 in narrative 3. However, considering that examples of learning arising from social conflict in the data sets were few and that the learning in question was largely 'potential' and inferred, maintaining distance from collaborating pupils in the face of social conflict presents a risk to curriculum learning. Maybe too big a risk. The next section discusses the nature and frequency of learning evident in the data.

7.2.2 The nature of emergent learning

7.2.2.1 Emergent learning appears to be limited to 'potential' and 'tangible' forms.

Perhaps the most significant observation about the emergence of learning was that visible instances of learning (potential, tangible or elaborated) were rare. Learning incident timelines in all three narratives indicate that learning surfaced and became observable at intervals and somewhat fleetingly across the duration of each episode. Field note data also suggests that learning which emerged was not fully formed, but needed structure imposed upon it to become crystalised or articulated. One example of this was episode Tuesday A, in which just three visible incidents occurred in twenty minutes. This finding is no surprise. Even in the ‘what works’ literature, acknowledgement that learning does not occur on-cue in neat packages is common. Hattie (2009) for example, writes that learning can be spontaneous and individualistic: A ‘timeworn, slow and gradual fits-and-starts kind of process’ (p.2). Ewens and Cammack (2019) point out that learning operates on invisible as well as visible levels and Alexander, Shallert and Reynolds (2009) note that learning changes are often tiny and imperceptible. Bransford, Brown and Cocking (2000) discuss a possible reason for these characteristics, that learning involves processes which themselves prevent learning from occurring quickly or in a smooth upwards trajectory, for example group interaction. As described in Chapter Two, the generative and recursive nature of learning (Guanglu, 2012) makes it always a process of organising, reorganising, constructing, reconstructing and refining existing knowledge and understanding. Much of this occurs at levels not accessible to observation (neurological, cognitive schematic) or simply remains formed but unarticulated.

However, analysing the data through a CAS lens encouraged inferences that learning may be taking place below the surface; what I termed ‘potential learning’ and signs that learning may soon become visible; what I term ‘becoming-learning’. Cobo and Moravec (2011) refer to this as invisible learning, advancing an argument which correlates with findings from this study, that invisible learning emerges when control structures diminish. They argue that the purpose of top-down control is to make learning visible, but that when control structures are weakened or removed, questioning, curiosity and serendipity (among other characteristics) emerge. This implies that centralised structures imposed by curriculum, assessments and the goal-orientations of teaching may prevent ‘potential’ or ‘becoming’ learning from surfacing. The data partially supports this idea. All instances of learning emerging from decentralised group collaboration, without adult intervention, were either ‘potential’ or ‘tangible’, but in no instances were they ‘elaborated’. One key moment of ‘elaborated’ learning coincided with adult interaction (episode Monday A) suggesting that expert scaffolding helps extend 'potential' and 'tangible' learning towards 'elaborated' learning. In an example from learning narrative one, pupil 20 articulated his later understanding about measurement on a MoL post-it note, aided by the distilling effect of adult support. It is likely that moments like this in which learning becomes 'elaborated' and observable are also the beginning of the permanent or semi-permanent changes which learning is believed to represent (Ewens and Cammack, 2019, Alexander, Shallert and Reynolds, 2009; Biesta, 2009; Bransford, Brown and Cocking 2000; Lefrancois, 1999). Where the data correlates more precisely with Cobo and Moravec's (2011) hypothesis is in the proposition that invisible aspects of learning need autonomous, open, bottom-up opportunities in which to germinate. If this is so, then setting the conditions which facilitate invisible aspects of learning, sensitivity to the signs that learning is emerging, the ability to infer the presence of invisible learning and knowledge of how to capitalise on it are necessary teacher skills. Data indicates that 'potential' and 'tangible' learning emerged in predictable and unpredictable ways, for example from more knowledgeable pupils sharing what they knew (pupil 12 in Monday A), because of social conflict (pupil 20 in Monday B), from attempts to articulate knowledge (pupil 17 in Tuesday B) and from incorrect assertions (pupil 19 in Monday C). What each of these examples have in common is that the learning, or signs of possible learning, emerged from decentralised, partially autonomous interactive episodes between pupils. A particularly interesting example was pupil 19's hypothesis (narrative 2) that joining two bottles together would make the rocket go further. There was sound logic in his reasoning (more space inside the rocket for more water) however, though the idea eventually took hold within and beyond his group, it turned out to be incorrect. Pupil 19 eventually developed a useful working understanding of the physics involved but got there via a misconception. This is illustrative of a typical characteristic of learning, that it does not progress upwards in a steady trajectory of understandings building on understandings. Rather, it is characterised by false starts, dead ends, twists and turns, peaks, troughs and plateaus. One could speculate that pupil 19 would not have arrived at his eventual understanding without the initial misconception. A CAS lens also offers insights about pupil 19's learning, arising as it did out of local autonomy. The shifting social dynamics of the group, the autonomous actions of the group members, the group's eventual adoption of his idea, failure during the prototype testing and realisations which followed were to some extent products of bottom-up system autonomy. Top-down control was present, tangible in the structure of tasks, time limits imposed on group activity, tacitly understood expectations about productivity and classroom behaviour and occasional presence of the teacher, however within and between these boundaries learning can be said to have emerged. Doll's (2000) assertion that

> 'The framework of teaching and learning can break away from the cause-effect framework that learning is the direct result of teaching and the superior-inferior relation between teaching and learning, so as to turn to another mode that teaching is attached to learning (…)'.

was evident in the data. The idea of teaching being 'attached' to learning implies a loose causality in which features of teaching (in this case the grouping, the tasks, the location, the preparation, the resources, teacher proximity) set the conditions within which learning might emerge in decentralised group structures. I would argue that causality is not the problem when attempting to describe the learning-teaching nexus; mechanistic causality is the problem (see section 7.2.2.2). Teaching after all is a significant part of what causes learning, but it cannot *produce* learning on demand. Evidence for this was seen in the MoL data showing that moments where self-identified learning was articulated and recorded were often several hours (or days) after the associated activities and in video episodes where learning appeared to be supported by unplanned-for events. Teachers have considerable bandwidth to control and oversea how their classroom systems operate. However, even in the most centralised classrooms, Johnson (2016) has pointed out that much goes unnoticed by teachers and based on the data, I would argue that within these spaces learning can emerge, sometimes unexpectedly. The data has several examples of this, including in narrative one, where pupil 10, 12 and 24's learning about aerodynamics appeared to be supported by a spontaneous eruption of humour. In another example from the same episode, it seems logical to presume that pupil 12's prior experiences of flying and conversations with his father about aircraft carriers could have exerted a tacit or residual influence on his thinking and understanding about drag. These examples lend weight to arguments that learning is accumulative, but not necessarily linear, and certainly not predictable. This supports Doll's (2000) call for the causal relationship between teaching and learning prevalent in 'what works' discourse to be re-evaluated. A realignment of causal conceptions of teaching and learning (a de-mechanising?) may enable teachers to apply the situational sensitivity necessary to notice learning emerging in 'potential' and 'becoming' forms.

Notable across all learning narratives was the lack of any clear correlation between proportion of on-task interactions and frequency or designation of learning which emerged. In some episodes evidence of learning was minimal despite relatively high proportions of on-task interaction. In others, learning was more frequent and designated as 'tangible' or 'elaborated' despite lower proportions of on-task interaction. In episode Monday C for example, 50% of all interactions were on-task yet there were only two 'potential' learning incidents. Conversely, in episodes Monday B and Tuesday A on-task interactions were only 7% and 11% respectively, however both registered similar or greater frequency of visible learning incidents as Monday C. Episode Tuesday B registered on-task interactions of only 14%, however there were seven learning incidents, including two 'tangible'. This indicates something interesting; that learning is not (solely) a function of 'being on-task'. Similar to assertions made in section 7.2.1.3 about social conflict and learning coexisting, the data indicates that learning persists even when conversation between pupils is not about the prescribed task. It may even be the case that off-task interactions somehow facilitate learning. Convincing evidence for this is difficult to locate in the data, however there were examples of humour giving rise to ‘potential’ learning incidents (e.g., episode Monday A). Some episodes were characterised mostly by off-task interactions with on-task utterances surfacing only occasionally. In some instances, pupils’ focus was clearly both on and off-task almost simultaneously, illustrating the pluriform nature of human interaction and whilst there is no concrete evidence for this, it is tempting to conclude that off-task interactions did not simply interrupt learning, but somehow also occasioned it.

Alongside findings from Rosenshine (2015) that whilst it is typical for only 40% of classroom time to be spent engaged in academic activity, the 60% of off-task activity negatively impacted productivity during the 40%, the literature contains some support for the idea that off-task behaviours can support conditions for learning (Dyson, 1987; Baker *et al.*, 2010; Sullivan and Wilson, 2015). Langer-Osuna (2018, p.1) confronts what she calls the ‘myth that all off-task interactions’ are ‘detrimental to learning’ arguing that off-task interactions have an important role to play in developing pupils’ identities. She argues that pupils do not simply *bring* themselves to learning activities, but *construct* themselves through them, positing that different pupil identities and positionings open opportunities for learning. Langer-Osuna’s description of how authoritative or subordinate identities create conditions for sharing or receiving of knowledge correlates with instances in the data where salient pupils shared what they knew (e.g., pupil 12 episode Monday A). Correlating most closely with the data from this study is Dyson’s (1987) finding that off-task behaviours can take tasks in new directions. Yonge and Stables (1998) also argue that the distinction between on and off-task interactions is difficult to determine since both can be productive sites for learning.

All three learning narratives include instances where activities apparently took on new directions because of interactions not directly related to the task. In most cases these were conflict related, however in episode Tuesday A procedural interactions concerning what to do were indicative of learning, revealing reasoning which shaped the course of interactions later in the episode. Many of the 30% of miscellaneous interactions in episode Monday C were silliness between pupils 11 and 16 which, whilst not directly causing any observable learning, were to the exclusion of pupil 19, who was attempting (without success) to explain his idea. Pupil 19's subsequent circumventing of the group by talking to the teacher could be viewed in terms of Langer-Osuna's (2018) hypothesis that pupils use off-task interactions to position themselves and others as part of identity formation. In this instance pupil 19 was positioned as an outsider and considering his decision to talk to the teacher and the later influence it had on his own and other groups, it seems reasonable to presume that the off-task interactions had considerable (eventual) influence on learning.

Agents in a complex system affect one another's behaviour through their interactions. From a complexity thinking point of view, pupil-pupil interactions within the system (group, class, school) are mutually influential, irrespective of whether they are on or off-task in nature. A complexity lens does not discriminate or attach more value to one than the other. Interactions in a CAS are more, therefore, than merely utterances occurring in the same time and place; interactions change the interactors and shape future action and interaction. Given sufficient autonomy and group diversity, local interactions among neighbouring pupils are likely to fluctuate on and off-task and every interaction (including non-verbal interactions, as with pupil 13 in episode Tuesday B) will determine as yet unknown future directions for the collective. Signals sent and received by pupils during group activity influence thinking, behaviours, decisions, utterances, tone, body language etc (Jacobson, Lewin and Kapur, 2019) and are recycled via feedback loops (Sullivan, 2009; Davis and Sumara, 2006;

Semetsky, 2005). Information exchanged when pupils collaborate does not travel linearly or follow a linear input-output model, but in networked and recursive patterns, producing unpredictable outcomes which feedback and give rise to new directions. Such new directions may or may not be task-related, curriculum focussed or desired by teachers. In this sense, complexity thinking proves to be descriptively useful, in that it helps to identify how and why a system is behaving in particular ways, but its power to derive useful recommendations for teaching is hampered in the classroom context by the necessity for pupils to learn certain things, not just anything. Off-task behaviours and interactions unquestionably hindered individual and group learning at times by preventing elaborated interactions from forming, shifting collective focus away from curriculum objectives or simply getting in the way and dominating airtime. This is the risk of autonomy. However, off-task-ness also sometimes gave rise to emergent learning opportunities. Complexity thinking provides a useful framework for understanding how this happens, but whether the potential for useful emergence is worth the risk that little of curricular value will emerge is a judgement call.

7.2.2.2 Decentralised classroom structures have CAS-like characteristics, though not consistently

In this study I have used four key CAS characteristics (self-organisation, emergence, non-linearity and transcendence) as tools for data analysis, and from them derived a working definition of complex adaptive classroom system (CACS) for the purpose of comparison with the case study classroom:

A system containing multiple autonomous, interacting pupils, whose inter-relationships create networked, emergent, non-linear behaviours from which self-organised change (learning) emerges.

Analysis of the data revealed a range of dynamics in-keeping with the CACS characteristics highlighted here, and in the literature. For example, through interaction, unplanned behaviours emerged which reinforced learning, as illustrated in episode Tuesday A when the group began throwing their rocket. Individuals (and in some cases the group and the class) learned things that were not specifically planned for by the teacher, for example pupil 19 in episode Tuesday A whose group learned inaccuracies which were later challenged and adjusted through experimentation. Individual and group learning were not always linear, influences came from outside the class system, pupil interactions created feedback loops which initiated new directions, activity, interaction and learning moments did not always occur with regularity or logical progression. Pupils were constantly affecting one another, and information travelled between individuals following non-linear routes, as in the case of episodes Monday B, Monday C and Tuesday B in which interactions created bifurcations which introduced novelty. Salience was an unpredictable and self-organising phenomenon which itself has emergent qualities. Disruption, competition and conflict introduced 'edge of chaos' states which in some instances were sites for emergent learning. Learning was partly built on short range relationships where neighbouring pupil interactions shaped small groups and small groups shaped the whole class to an extent, as ideas spread across groups and pupils in different groups discovered similar things through separate experimentation. The decentralised group structure created ambiguous boundaries between individuals and small groups and interactions did not remain within groups but travelled across nested levels (individual, group, class). However, these characteristics tended to be the exception rather than the norm and where emergent qualities surfaced, their effect was rarely pronounced.

Table 7.1 presents my judgements and commentary about the applicability of each of the key concepts in this CACS definition to the case study classroom. Applicability has four designations: Broadly applicable, partially applicable, marginally applicable or nonapplicable, which are based on the assumption of classroom organisation moving between centralised, decentralised and distributed organising principles. My judgements carry the caveat that conditions for emergence were planned for in this study and therefore the applicability of each concept refers only to the research week. Applicability to other classrooms will depend on how top-down and bottom-up organising principles are manifest.

Key concept from complex social system definition	Applicability to classrooms as defined in this paper	Researcher commentary
Autonomous agents	Partially	Pupils were autonomous within the structures of groupings, task, time limits, location and classroom rules and expectations. They were largely unmonitored.
Interacting agents	Broadly	Autonomy showed itself in the choices pupils made about their interactions. Interactions were largely unconstrained, but closed tasks may have limited the richness of interactions and the possibilities for emergence.
Producing non-linear system behaviours	Marginally	There were indications that interactions produced non-linear feedback loops, but this was constrained by central structures described above. This was dictated by the degree to which group systems were open and generative. Less open tasks produced less interactions which limited non-linearity.
Self-organising	Marginally	The dominant organising principle at work in the classroom was top-down rather than bottom-up. Self-organisation appeared

		occasionally despite this. Self-organisation was not occasioned deliberately. It seemed to emerge through the gaps.
System change (learning) emerges across different system levels	Marginally	The class system 'learned' in so much as patterns of shared knowledge moved through levels from individuals to group to class, but this was more a consequence of top-down then bottom-up structures.

Table 7.1. Core concepts from CACS definition – applicability to the case study classroom.

Table 7.1 indicates that whilst CAS characteristics were observable, they were not the presiding organising principle in the classroom, despite deliberate efforts to occasion them. This included giving greater than usual autonomy to pupils, open tasks, structures designed to encourage interaction and dialling back teacher control. Some of these conditions were more successfully realised than others and emergence revealed itself, but only just.

The data highlight that the extent to which complex characteristics were free to unfold was largely a function of teacher control. It also indicates that emergent self-organisation and centralised control cannot easily coexist. The more autonomy pupils were given through decentralised and distributed structures, the more the classroom took on CAS-like characteristics. The more centralised the structure, the less CAS-like the classroom was. Though as Radford (2008) and Hardman (2010) have pointed out, even the most tightly controlled and predictable systems are complex when viewed at high enough resolution. At resolutions accessible to human observation in a study like this, the degree of top-down structure determines the complexity of the system. Viewed at neurological resolution for example, Holland's (1995) explanation that the combined interactions of less complex agents (e.g., neurons) in a system produce complex behaviours at higher levels (e.g., individual humans) is self-evident. However, viewed at the resolution of the individual pupil, it is not self-evident in this data that pupil-pupil interactions produced complex emergence at group or class levels in any circumstances. Learning entities emerged, but patterns of emergence were harder to locate. Learning traversed classroom levels, but patterns of emergent behaviours within the classroom collective were not visible in the data. Conduciveness to complex emergence appears to rest on whether pupil autonomy or teacher control is the prevalent organising principle in the classroom. Sullivan (2009, p.185) uses the term 'keystone species' to describe the influence that teachers have over the openness of their classrooms to complex behaviours, 'influencing, but not determining precisely what will happen.' This conception comes close to (but stops short of in my view) Jorg's (2009) notion of teacher as fellow traveller and means that if there is value in what emerges when conditions invite complex classroom behaviours, then teachers are in the perfect position to invoke such conditions and facilitate learning through emergence. Resnik's (1994, p.70) assertions that complex behaviours are 'the outcome of rule-following agents interacting with the environment' and that 'modification of the environment is one way in which that behaviour can be changed' are relevant here. The classroom and its decentralised structure seemed to want to behave in complex ways, and there are signs in the data that learning would emerge from bottom-up sources given the right conditions. For this to be amplified however, the environment would need to be modified towards greater pupil autonomy, which as discussed poses risks for teachers. Haggis (2008, p.165) points out that 'what emerges will depend on what interacts' and what (or who) interacts is determined to a significant extent by teacher choices. Dalke *et al.,* (2007, p.6) suggest that the teacher's role is to 'create the kind of rich environment within which productive organizations can emerge from the interactions of all participants.' Davis and Sumara (2006) advocate distributed control, in which some of the centralising influence of the teacher becomes disseminated outwards towards pupils, as a potential means of occasioning emergence (Davis, 2004). However, Kuhn (2008) is critical of a prescriptive approach to complexity research, in which researchers talk of creating conditions to facilitate emergence. She posits that complexity offers insights about ‘how things are’ (p.178) and criticises attempts to move from *is* to *ought* when researching educational systems. Despite these objections, the urge to consider how a system could be nudged to encourage more complex behaviours has been strong among educational complexivists, a consensus being that one must give up control if complexity is to happen (Kelly, 1994), or to use Doll’s words (1989, p.67) classroom organisation needs ‘more dancing and less marching’. Relinquishing control demands different pedagogical approaches. What could be termed ‘managed complexity’ requires attunement to what is and what might be. In all three narratives the course of learning was dictated by circumstances. Sometimes small, fleeting events subtly changed the course of learning for everyone, and it is interesting to speculate about (though impossible to ascertain) what may have emerged and how learning may have been different if events had been different. For example, if pupil 20 had been in a more cooperative mood in episode Monday B, or if just one group member in episode Monday C had listened to pupil 19’s idea. These ‘what if?’, or ‘sliding door’ moments are fixed and singular (there is no parallel universe in which learning was more or less elaborated than the current reality), however they do illustrate how learning can hinge on the seemingly insignificant events, or to paraphrase an adage, small hinges swing large doors (Anon). Knowing this may encourage teachers to attend to small events and perhaps consider how they might be managed or occasioned; or when learning may benefit from being revisited.

7.3 Conclusion

Evidence of emergent characteristics of learning exist at the nexus of freedom and constraint. My field notes are dominated by observations that opposing forces of centralisation and decentralisation, as orchestrated by the teacher, were the primary variables which either unlocked or suppressed emergent behaviours within the classroom. The data indicates there may be sweet spots between sources of coherence and disruption in which autonomy is sufficient for novelty and innovation and constraint sufficient to avoid all-out havoc. This was particularly evident in learning narrative three. In some episodes, more productive entities may have emerged had the system been more open, e.g., through less closed tasks or longer time allocations. In others, more structure may have generated more useful emergence. As Waldrup (1992, p.295) states, whilst frozen (centralised, predictable) systems can benefit from ‘loosening up a bit’, turbulent systems ‘can always do better by getting themselves a little more organised’. If there is value in what might emerge from decentralised classroom structures (and the data suggests there may be), then considering how teachers could navigate the risks and attempt to occasion emergence is worthwhile. Discussion of key themes arising from the data analysis leads me to advocate for what might be termed ‘managed complexity’ which is elaborated upon in Chapter Nine.

8.0 Limitations

Inevitably there were limitations in the design and execution of this research. This chapter highlights limitations which had the most significant impact on the findings, reflects on their impact and considers how future research could overcome them. Limitations fall roughly into three categories, conceptual, methodological and analytical, however these categories overlap considerably.

8.1 Conceptual limitations

Using a CAS framing has provided a vocabulary and range of concepts which have helped bring narratives of learning into relief. It encouraged a granular analysis of interactive episodes which yielded insights inaccessible to lower resolution analysis. Subtle turning points in the learning were only evident after repeated viewings and analysis of the video data, which demonstrated the importance of research of this type to illuminate aspects of classroom learning. The study has conceptual limitations, however. Repeated reference has been made in Chapters Two, Three and Seven to ontological, epistemological and axiological tensions between the values and goal directed nature of education systems and the values-neutrality and non-goal-orientation within conceptions of CASs. Nowhere is this dichotomy more evident than in the differences between the 'what works' pragmatism which dominates much of the literature and research on interactive learning and the morally neutral system modelling which characterises complex systems discourse. Therefore, there was an underlying incongruence between the subject and the object; between the phenomenon under scrutiny and the framing of that scrutiny. Deriving complexity-inspired recommendations for how teachers exercise leadership in classrooms, when teacher leadership in classrooms is precisely the organisational mechanism which appears to counteract complex emergence felt contradictory. When thinking like a teacher, I want to know ‘what can I do to help every pupil reach their learning potential’? When thinking like a complexivist researcher, I want to know ‘how does the system organise itself when pupils have sufficient autonomy’? However, mere description of reality is insufficient in a professional doctorate which privileges recommendations for improving future practice. Herein lies a paradox. The requirement to make ‘what works’ pedagogical recommendations using a conceptual framework which challenges the legitimacy of the ‘what works’ philosophy pulled the research (and researcher) in opposite directions and placed limitations in the capacity of complexity thinking to generate professional advice commensurate with the current educational landscape.

In addition, the lack of any unitary theory of CAS (Kuhn, 2008) necessitated deriving a framing, in the knowledge that it would be an imperfect tool. Seeking CAS insights about small group classroom learning when there is no consensus about CAS behaviour is to invite a certain conceptual fuzziness into research method, analysis, conclusion and recommendation.

8.2 Methodological limitations

My attempts to capture the pluriform and distributed causalities of a busy, mostly decentralised classroom fell short of my initial ambition. The data collected barely scratches the surface of what would be required to thoroughly document and assess complex, emergent classroom behaviours. It is certain, though impossible to pinpoint precisely, that my physical presence in the classroom, my interactions with pupils and the presence of cameras and voice recorders both gave rise to, and suppressed, behaviours and phenomenon of interest to the study. I, as the researcher, became a part of the complexity of the classroom system, causing perturbations and contributing to the construction of the present and the future. My complex realist position (see Chapter Three) acknowledges causality at all levels of human social systems, but also the impossibility of attributing single causes in complex collectives. Therefore, disentangling contributions my presence made to the behaviour of the system was impossible, further limiting attempts to accurately describe and link behaviours and learning in the classroom system.

Collecting data on complex phenomena in a human social system is difficult. Video footage, self-reported MoL, pupil interviews and researcher field notes whilst not insubstantial, captured only a small fraction of what was occurring at any given moment. The technology to map more of the complex realities of the classroom, for example through a greater range of video camera angles, background noise reduction microphones or giving pupils individual radio microphones, was not available. By selecting camera positions, I selected certain fields of focus for the study. Different choices at the time would have captured different fields and the data would have presented different accounts, possibly depicting more instance sof emergent learning, possibly fewer. Haggis (2008) points to this when stating that complexivist researchers must concede to the limits of what can be described or explained. As such, the accounts presented in these three learning narratives are flawed and incomplete. Each tells a particular story derived from the data and I used my judgement to determine the best possible account in response to the research focus and questions, but each narrative has other potential stories to tell.

In hindsight, the data would have been strengthened had it included more footage of pupils testing prototypes outside. The openness of the physical space, the practical and experimental nature of the activity and interactions may have been more conducive to emergent behaviours and offered more scope to the CAS framing. Reflections on the data revealed that it may have been advantageous to follow certain individual pupils through the research week to develop a picture of their learning and their influence on system learning over time, as they travelled the topography of activities, contexts, groupings, organisational structures and agent interactions. The data includes several examples of potential learning which are noted but not pursued and an approach such as this would have enabled greater analysis of how learning moved from potential to tangible to elaborated over time. Limitations imposed by time, logistics and methodological decisions during the research week meant that worthwhile data was excluded from the learning narratives. This included instances in which pupils were interviewed about a MoL they had posted midweek, which was of partial interest to the study, only for the same pupil to post a considerably more insightful MoL later in the week without being interviewed about it because that pupil had been 'ticked off' the interview list. In some cases, later MoL postings built upon, extended or clarified learning articulated in earlier MoLs, but were not captured. Closer attention to daily MoL data and undertaking all pupil interviews later in the week may have avoided this. However, my commitment to interviewing a wide range of pupils led me to limit interviews to one per pupil.

Activity during the research week was deliberately configured to encourage emergence, though this was only partially successful. As discussed in Chapter Four, activities, resources and classroom structures were less open than originally planned, meaning that the data captured the classroom as it had to be, rather than how it could have been. I had intended for the pupils to define the terms, objectives and outcomes of the learning iteratively through their activity. However, I had to operate within contextual constraints, which were less open to pupil autonomy than originally hoped. I suspect that greater openness would have occasioned more observable patterns of emergence emanating across levels within the classroom. Nevertheless, as discussed in Chapter Seven, there is no certainty that learning would have been more visible; it may well have been less so.

Self-organisation takes time to unfold. This week-long study was not long enough to observe emergent patterns unfold substantially at small group or classroom level. Observing and capturing complex, networked behaviours was possible, however recording the ways these behaviours gave rise to organised patterns of adaptation, as is typical of CAS, was not possible over five days. The week-long duration also meant that judgements about pupils and their positions in social hierarchies were formed based on my instinct and teaching experience, rather than more protracted observation. Consequently, the data tells a story of possibility and potential, illustrating that some of the tendencies and necessary behaviours for complex system adaptation were present, without being able to document how these were realised as patterns of adaptive emergence within, between and beyond the small groups.

8.3 Analytical limitations

Chapter Five presented a range of limitations in the data analysis instruments and processes and highlighted their potential impact on the findings. In this section I focus on ways that the complexity framing influenced, and set limits on, data analysis. The necessity to give definition and form to the idea of a CAS meant settling on a particular CAS framing. This orientated my analysis deductively in that as I was examining the data for qualities present in the framing. However, my analysis also became inductive because unanticipated phenomena emerged from the data. I was seeking evidence of emergence, however emergence by its nature 'emerges', and predicting what might emerge was not possible, perhaps why Byrne (1998, p.7) describes complexity as being 'founded inductively'. As discussed in previous chapters, researching complex system behaviours is challenging and for this reason I chose to employ a mixed methods approach to piece together the most comprehensive picture of group and classroom systems that I could within the scope of the study. Despite this, there was far more going on in each group work episode than could be observed or interpreted through my analysis of them. Interactive subtleties, undetectable histories and tacit causalities meant I was forced to become more concerned with effects than with causes, many of which are inferred and tentatively articulated. My responses to the research questions therefore, despite emerging from narratives combining multiple data sets, were based on partial and incomplete meanings. An occupational hazard for complexivist educational researchers according to Haggis (2008, p.159) who states, one must 'accept limits to what can be described or explained'.

A limitation common to observational studies is the absence of any counterfactuals. The situated nature of learning means that when asserting the presence and significance of emergent learning it was not possible to know whether more elaborated learning may have emerged in different circumstances, for example under rote learning conditions. Whilst I was careful to present realistic interpretations of emergent learning and to be realistic about the forms it took and its significance, I acknowledge that what I observed was a slice of reality in the circumstances of the moment and that there was a risk of appearing to lionise somewhat fleeting and inferred instances of emergent learning. This limitation is hard-wired into situated research contexts; it is a limitation, nonetheless. Findings from this study have made a small contribution to the question of whether a CAS framing can reveal worthwhile insights about learning. However, with the caveat that there is no single approach, no silver bullet, which can yet offer definitive answers, my research beyond this study will adapt in light of lessons learned.

8.4 Ways forward for future research

Based on limitations presented here and in Chapter Five there are several adaptations to focus, judgement and practice which I will apply in building on this study. Despite the challenges of seeking to identify and describe complex classroom behaviours and their consequences for learning, I remain convinced that there is merit in the complexity framing and that a complexity lens has potential to reveal insights about which traditional, more reductionist approaches cannot. A finding which I believe merits further investigation is pupil salience. Though only touched upon in this study, forms of salience appear to have complex adaptive qualities in that they represent a sort of classroom subculture not governed by teacher actions and were perhaps the closest phenomenon to emergent self-organisation which the study revealed, bearing considerable influence on cultures and learning. A future study would examine this emergent phenomenon through a complexity lens. Future studies will require data episodes to be longer in duration than the 6-20 minutes in this study. Data should include multiple episodes of the same pupil groups across a variety of task-types, over several days to understand ongoing effects of salience on learning journeys from one episode to the next. A more systematic approach to pupil interviews, including group interviews, may produce richer narratives, lessening 'context-stripping' (Guba and Lincoln, 1994) effects which reduce complex phenomena to simpler forms. I have learned a great deal which will aid my planning for future research, including judgements about pupil age phase, teacher collaboration, tasks and timings and technology. I also understand complexity more comprehensively now than I did when I embarked on this project, meaning that future research plans will be informed by more comprehensive appreciation of how complex social systems are variously conceived in the literature and how complexity may reveal itself in a classroom.

9.0 Conclusions

9.1 Introduction

This chapter draws on discussions of the key findings in Chapter Seven to present conclusions which illustrate the contributions this study makes to the field and address the research questions. I present recommendations for teacher development and initial teacher education based on the idea of 'managed complexity'. Returning to the political framing which partly motivated this research, I also consider what the findings mean for the 'what works' epistemology. Finally, I present my reflections on undertaking this study.

My claims to knowledge are:

1. That learning has emergent qualities. Given the right conditions it will surface, sometimes at unexpected times in unexpected ways. These conditions are largely a function of the degree of centralised control exercised by teachers.
2. That emergent learning needs to be nurtured by teachers in order to become elaborated.
3. That pupil salience has emergent, self-organising properties emanating from pupil diversity which influence individual and group learning.
4. That a CAS framing can illuminate and provide a vocabulary for discussing characteristics of decentralised classroom learning which might otherwise remain tacit.

The purpose of this study was to use complexity thinking as a tool to analyse classroom learning. Acknowledging that no single definition of CAS exists, I developed my own CAS criteria drawing on properties found most commonly in the literature and which applied most clearly to a primary classroom. These were used as a lens through which to analyse interactive classroom episodes in pursuit of novel insights about small group learning and the utility of a complex classroom system framing. Intersections between these system properties and what the data revealed have been highlighted in Chapter Six and discussed in Chapter Seven. Below, they are articulated in response to the research questions.

9.2 Addressing the research questions

RQ1: To what extent can learning be said to have 'emerged' within small group classroom activity?

Analysis of the data suggests that observable learning is partially, but not entirely, dependent on central governing structures (primarily the teacher) and as such, can be provoked to emerge bottom-up through autonomous, decentralised pupil interactivity. Attempts to trace antecedents of learning incidents revealed that teaching and learning do not always share spatial-temporal contiguity, that learning is a process (or series of networked processes) not an event and that a range of factors may contribute to the directions that learning takes. Significant among these factors are group composition, including the presence of salient individuals, density and quality of interactions, physical environment and balance between autonomy and constraint. Evidence from the data suggests that learning which is more than the sum of individuals' knowledge can emerge at the nexus of these factors. If the opposite of emergence is the centralised, linear transmission of knowledge from teacher to pupils, then decentralised classroom learning certainly has emergent qualities. Pupil autonomy appears to play a significant role here. As discussed in Chapter Seven, spontaneous patterns of organisation among interacting pupils, when allowed, can facilitate emergence. However, the values and goal orientations of classrooms means that not everything that emerges is welcomed or valued. This is a challenge faced by all decentralised social networks. Degrees of autonomy will produce degrees of self-organisation but what emerges may be more or less desirable. In the interest of encouraging desirable learning which is congruent with curricular aims teachers impose centralised management on the classroom system, which tempers emergent learning. To a certain extent, interactive pupil autonomy and the emergent self-organisation it engenders are functions of the degree-centrality of the classroom system. Learning will emerge bottom-up if teachers manage their classrooms in ways conducive to this, but not all that emerges will necessarily be of obvious educational value. To some extent then, emergence and teacher control find their limits in one another.

In addition to evidence that learning emerges at the level of the individual, there were some instances captured in the data where individual realisations or ideas found their way upwards and influenced learning of the whole class. These few examples illustrated how learning at individual pupil level can produce aggregate changes in learning and behaviours at higher levels in the classroom system, including among small groups and the whole class. In this sense, individual learning can be said to contribute towards classroom system learning and vice versa; individuals learn because of their interactions with their group, groups learn because of individuals' learning, the class learns because the groups learn, and so on. However, observable emergent learning of any sort was scarce in the data. Instances in which learning surfaced noticeably were occasional and brief, suggesting that visible emergent learning is the exception rather than the rule in decentralised class structures and that much remains below the surface. There were no observable examples in the data of 'elaborated' learning emerging without the presence and influence of an adult, suggesting that whilst learning can be said to emerge, emergent learning has limitations when evaluated against curricular intentions. This conclusion is elaborated upon in the next section.

RQ2: What are the characteristics and value of 'emergent' learning?

Learning which emerged from pupils' co-dependence and interconnectedness had some distinguishing characteristics. The absence of any pupil-only instances where learning was extended through explanation or reasoning suggests that emergent learning may be limited to lower-order forms. Notable examples include the incomplete, contingent and only partially formed characteristics of learning which emerges from the bottom-up. It appears to be not-yet-distilled, unrehearsed, unready for articulation and therefore difficult to pin-down. Emergent learning, therefore, could be usefully conceptualised as emergent in and of itself; as 'becoming-learning'.

The value of 'becoming-learning' is self-evident. Instances of teacher supported 'elaborated' learning build on what is 'becoming'. In this sense emergent learning forms the foundation of future secure learning.

RQ3: What conditions encourage 'emergent' learning?

The data suggests a range of classroom conditions which could occasion emergence. However, considering the conclusion in section 9.2.1 that not all that emerges bottom-up from classroom interaction can be equally valued educationally, it is necessary to consider how the most educationally valuable emergence can be encouraged. Based on analysis of the data, Table 9.1 presents a summary of eight classroom conditions which have the potential to encourage the emergence of learning.

Condition for emergence	Explanation	Teacher knowledge
Collision of ideas	Disagreement, argumentation and the interaction of differing opinions can be productive sources of emergent learning. Resolutions may be more than the sum of individual pupil contributions.	Designing tasks fertile for counterpoint. Knowing *how* and judging *when* to centralise or decentralise

		organisation and autonomy and understanding the consequences. Attunement to apparently 'off-task' behaviours/interactions/utterances and openness to learning emerging from unexpected places.
Locating 'sweet-spots' between top-down and bottom-up organisation.	Both 'clockish' and 'cloudish' modes of classroom organisation risk neutralising valuable learning opportunities. Balancing positive and negative system feedback. Fruitful pedagogies capitalise on balance between these two organising principles.	Knowing *how* and judging *when* to centralise or decentralise organisation and autonomy and understanding the consequences. Sensitivity to 'teachable moments' Thinking non-linearly. Not always asking *'if…then'* questions about learning. Sometimes asking *'what if…'* questions. Skilful assessment of social conflict and its potential to occasion novelty and innovation. Not intervening too quickly to close it down.
Distribution of salient individuals.	Knowledge-based, social or personality-based salience is considered when grouping pupils.	Knowledge of the types of salience pupils may bring to interactive activities.
'Becoming-learning' surfaces and is noticed by teachers.	Partially formed ideas must find ways to reach the surface because they represent the foundations of future	Confidence and competence in noticing and inferring signs of 'potential' or 'soon-to-be' learning.

	elaborated individual, group and class learning.	Enabling interactive episodes which encourage this. Understanding roles that teaching plays in occasioning learning (avoiding a causal, mechanistic conception) Sensitivity to small events upon-which learning may hinge.
Mechanisms for feedback loops between individuals, groups, classes.	Knowledge and ideas must leak out of teacher-pupil linear pathways to enable pupils to affect and learn from one another.	Comfort with knowledge and ideas moving between pupils. Deliberate decentralising of knowledge and idea production. Creating classroom structures which encourage the movement of knowledge and ideas between pupils and across levels (individuals, groups, whole class)
Multiple, multi-modal and networked activities.	Moments of learning emerge because of multiple sources, inputs and influences.	That learning is a process (or series of processes), not an event.
Pupils accustomed to autonomy.	Pupils need opportunities to acclimatise to the demands of autonomous, interactive group working.	That managing interactive collaborative activity is highly demanding for pupils and requires practice.
Timely and sensitive teacher scaffolding.	Interventions which capitalise on tipping points between potential and tangible/elaborated learning.	Sensitivity to signs of potential (or emergent) learning. Judging when to elicit elaborated learning. Eliciting reflection.

Table 9.1. Summary of classroom conditions for occasioning emergent learning.

Although, as Davis and Sumara (2006, p.152) point out, emergence cannot be ‘scripted or managed into existence’, the data suggests that the relationship between teacher imposed top-down control and bottom-up emergent pupil interaction may be significant in establishing conditions likely to occasion educationally valuable emergence. I propose that there are ‘sweet spots’ between top-down and bottom-up initiative in which pupils benefit from what both autonomous interaction and teacher scaffolding have to offer. Capitalising on such sweet spots will require teacher skills not dissimilar to those of a jazz leader who makes constant in-situ judgements about when to tighten and centralise control and when to loosen it and allow improvisation. Such situational awareness and responsiveness, as well as openness to learning originating from surprising sources, will be central to ‘expanding the space of the possible’ (Davis and Sumara, 2006, p.135).

Within the limits of what is practical and possible for teachers, consideration of factors which contribute to pupil salience and thoughtful distribution of salient individuals in group composition has the potential to create conditions in which learning may emerge from the bottom upwards. Awareness of and vigilance to the effects of system diversity and redundancy on pupil interaction, along with strategic planning for their distribution across pupil groups may also create conditions in which pupils’ ideas and shared/differing competencies will collide in a manner conducive to the emergence of learning.

RQ4: How useful is a CAS framing for analysing decentralised classroom learning?

It would be a stretch to call the classroom in this study a CAS, however the small groups and, to an extent, the whole class did display some complex behaviours. The networks of interactions between pupils, adults, resources and the environment were dynamic to a certain extent, produced uncertainties, were unpredictable in some ways and gave rise to moments of novelty. However, there was little by way of system adaptation because of the necessary centralised governing structure emanating from the teacher. Nevertheless, the findings suggest that there is utility in applying a CAS framing to decentralised classrooms analysis. A complexity lens can encourage researchers to look for learning-related phenomenon which traditional approaches do not and encourage looking in places, and in ways, that traditional research does not. As (and *if*) complexity applications to classrooms increase and as the field of education complexity becomes more defined and refined in its approaches, I predict that increasingly salient insights can and will emerge as a result of applying complexity thinking to the classroom. As technology develops, I believe complexity may at some point move classroom research beyond descriptions of teaching and learning as *not causally mechanistic*, towards better illustrations of why this is the case.

For teachers, the principal utility of a CAS classroom framing is the enticement to think non-linearly about teaching and learning and pause for thought about some well-established and intuitive assumptions about what causes learning and how best to occasion it. Recommendations in section 9.3 draw on suggestions in Table 9.1 of ways teachers and pre-service teachers might capitalise on the findings of this study.

9.3 Implications

The principal implication arising from this study is that there is utility in viewing decentralised classroom structures through a complexity lens. Using CAS qualities as points of reference has revealed some characteristics and tendencies of, as well as hunches about, learning which may have remained tacit to a non-complexity treatment. The merits and recommendations arising from these are similar for both teachers and pre-service teachers and are articulated below. Suggestions for how these might be implemented are presented separately in sections 9.3.1 and 9.3.2. These recommendations for teacher/pre-service teacher professional development are consolidated from the Teacher Knowledge column of table 9.1 above.

1. Understanding of the teacher's role in orchestrating conditions within which learning can emerge.
2. Sensitivity to signs of 'soon-to-be' learning and knowing ways to nurturing it.
3. Locating sweet spots between centralised, decentralised and distributed structures and judging when to transition between them.
4. Sensitivity to emergent learning conditions. Identifying them and occasioning them. This includes awareness of factors creating salience for pupils in different circumstances, monitoring pupil collectives for signs of salience and capitalising on these, developing tasks which are fertile for interactive counterpoint and taking the risk that productive conditions for learning can emerge from social conflict.

9.3.1 Managed complexity - Implications for teacher development

The principal implication for teachers arising from this study is a recommendation to introduce subtle shifts in thinking about classroom practice and pupil learning. This would include considering the potential benefits of loosening central control and allowing pupils sufficient autonomy for self-organisation to emerge, holding less tightly to evidence of pupils meeting learning objectives in unitary packages (which rarely happens anyway) and developing sensitivity to what else might be learned, openness to noticing that pupil salience is not limited to fixed notions of 'ability' but that pupils can be salient to collective learning in a variety of ways. Sensitivity to micro-events (including those seemingly indirectly related to learning) and their potential influence on individual, group and whole class learning (for better or worse) may prove a useful tool for teachers in understanding and working with learning's non-linearity. However, teachers tend to be well enculturated into 'what works' habits of mind and practice, and any challenge to this ethos would be likely to require unlearning some long-established presumptions about how teaching contributes to learning and about linear forces playing out in the classroom. Fortunately, several of the findings and inferences from this study confirm ways that many teachers will experience the classroom, as complex, non-linear and unpredictable. This means that if there is value in teachers rethinking their practice in these ways, honest reflection on the nature of the classroom as they experience it may be enough to motivate some to try.

9.3.2 Implications for Initial Teacher Education (ITE)

The principal implications of these findings for ITE concern the ways pre-service teachers (PSTs) are encouraged to conceive of relationships between teaching and learning. PSTs should be urged away from framings which locate learning as solely a linear product of teaching. Instead, they should be invited to adopt a more open and speculative mindset, exploring and investigating pluriform and interconnected antecedents of learning, including 'sliding doors moments' rather than expecting it to appear as a product following input. Understanding learning as a recursive process (or series of processes), not an event, is crucial to this. Little attention is given to these characteristics of learning in ITE provision, in my experience.

Developing appreciation of system-level factors, including teacher action, and their influence on learning would also strengthen pre-service teachers' pedagogical repertoire. In my experience, teaching and learning tends to be presented with much attention given to direct instruction, teacher modelling, questioning, task differentiation and individual scaffolding.

These are all important aspects of teaching, however, as the findings here suggest, learning also emerges because of system-level conditions over which teachers may also exercise degrees of influence. Creating classroom structures which encourage the movement of knowledge and ideas between pupils and across levels, knowing how and judging when to centralise or decentralise organisation and autonomy, and understanding the consequences, sensitivity to signs of potential (or emergent) learning and judging when and how to nurture it towards elaborated forms require judgement rarely discussed in ITE, in my experience. Professional judgement tends to be seen as something pre-service teachers acquire by osmosis whilst in the classroom; this is somewhat left to chance, however. Explicit teaching about the skills and attributes which enable sensitive, expert judgements about a range of classroom factors, including responses to social conflict, would prove useful. For ITE lecturers this would mean drawing on literature and research which is not typically included in ITE programmes, including topics such as teacher improvisation, intuition, situational and discretionary teacher judgement.

9.4 Why 'what works' only works sometimes.

The findings of this study present some challenge to conclusions concerning relationships between teaching and learning which arise from 'what works' orientated research and policy. It is evident that learning is more subtle, nuanced and multi-causal than is often accounted for in 'what works' policy frameworks and research inspired by 'what works' mindsets. 'What works' is predicated on learning flowing largely directly and predictably from teacher action, which it unarguably does to some extent, some of the time. However, these data illustrate how learning also emerges unpredictably and indirectly from teacher action, and from between the gaps of teacher intentions. 'What works' policy prescriptions fail to capture the complexity of the classroom and are therefore always destined to produce teaching and learning enactments which fall short of their promise. Research into classroom teaching and learning, characterised by what I have termed ‘soft what works’ mindsets, would also benefit from a more explicit and overt commitment to the reality that teachers, whilst influential, can exercise only partial control over pupil learning. Borrowing concepts and language from the complexivist literature, such as ‘occasioning’ learning and ‘emergence’ of learning, would help shift emphasis away from the more mechanistic interpretations of teaching and learning. The implications of this for those enacting and inspecting it are perhaps best characterised by continued frustration. This will form the basis for future discussion publications.

9.5 Researcher reflections

In this section I briefly reflect upon the experience of undertaking this research. I interrogate my position within the research and consider-out-loud how the process has transformed me as a researcher, an academic, a teacher and teacher of teachers. My aim is to achieve what Cunningham (2018) refers to as pensive professionalism; reflexive, open and undogmatic.

This research project was difficult. To paraphrase G.K. Chesterton, complexity in education has not been tried and found wanting; it has been found difficult; and left largely untried. Hardman (2010) has pointed out that complexity appeals to teachers because it appears to fit with how they experience the classroom and this was certainly the case for me, however applying a complexity framing to an empirical classroom study was, to borrow Eisner’s (1985, p.104) words ‘an inordinately complex affair’ in and of itself. One of the biggest challenges was forging and maintaining a *researcher* persona whilst immersed in an environment so familiar to me as a *teacher*. The instinct to revert into a teacher mode demanded constant self-monitoring and self-reminding about my purposes in the classroom and the need to manage my positionality away from teaching, towards observing and capturing. Whilst I left the primary classroom and became a university lecturer thirteen years ago, my teacher instincts returned immediately at the start of the research week, suggesting that I was still transitioning towards a researcher identity. Throughout the week I settled increasingly into the researcher role until adopting a researcher position became the default. Cunningham (2018) argues that professional identity is constantly evolving in response to new challenges we face and the challenge of undertaking this research study has caused my identity to evolve in some tangible ways. Firstly, the act of spending a prolonged period in a classroom as a researcher, not as the teacher, had a ratifying effect on my transition from the primary teaching profession to the field of academia. Secondly, whilst most of my academic work is teaching-based, undertaking this doctorate has caused me to view myself as a researcher, at least as much as a lecturer. Far from staggering to the finish line and never wanting to research ever again, I am energised to build on what I have learned and become a better, more regular researcher. Increasingly, I see my research and my teaching as interdependent, however. The reflective habits of mind engendered by empirical research, particularly with respect to complexity thinking, will strengthen my teaching as I incorporate findings from this study into aspects of my teaching portfolio. The fact of having pursued a research project from conception to conclusion has strengthened my convictions about the importance of research-informed teaching.

Related to the challenge of disentangling my identities as a teacher and a researcher, was the challenge of discriminating the sources of my knowledge whilst analysing the data. I had to reflect on the origin of every hunch, potential connection, relationship and inference by asking, ‘do I know this because it is evident in the data, or because of my extensive classroom experience?’ On occasions, the answer was the latter and it proved necessary to revisit the evidence to ensure my assertions were data-evidenced. Clearly, there are advantages to bringing professional knowledge to a research project. Clearly, there are also potential pitfalls. Apart from the obvious learning about the discipline which empirical research demands, this also speaks to the development of new professional identity. Discerning what is, and is not, data in a given study and locating boundaries between professional and research knowledge is central to understanding how research informs professional knowledge and to manoeuvring between elements of this hybrid identity. This insight has been particularly useful since recently beginning to lead and teach an undergraduate research methods module. To a large extent, undertaking this study has given shape and form to my longstanding reflections on teachers' professional work and pupil learning. This did not represent the beginning of my thinking deeply about teaching, learning, the classroom or how we prepare future teachers, however learning about complexity theory and problematising its applications to primary classrooms has enabled these reflections to coalesce around key ideas about complex social systems. There are a number of potential applications for my research findings within my current ITE teaching. Most significant are my sessions on classroom management, behaviour management, learning theory and my mentoring of pre-service teachers on placement, discussing teacher judgement and teachable moments.

I was first drawn to complexity theory because of its descriptive appeal and potential to portray primary classroom learning without reducing it to a linear product of teaching input. However, the effects of studying complexity have spread well beyond my conception of the classroom and to some extent, complexity thinking has become the dominant lens through which I evaluate all social realities. My aversion to reductionist portrayals of demonstrably complex phenomena extends beyond teaching and learning and, as explained in Chapter One, when evaluating social trends, ideologies, global challenges, activism and histories I am slow to impute simplicity and naturally sensitive to the complex, causally-networked, recursive and emergent qualities of events. I have become slower to demand answers or presume simple solutions and developed greater comfort with complexity and uncertainty. This ontological shift is the most significant personal and professional change that undertaking this study has occasioned.

9.5.1 Postscript: Reflections on complexity-sensitive empirical research *(post viva voce)*

Since completing this study I have reflected its positioning within the repertoire of existing complexity-inspired studies and the philosophical literature on complexity research in the social sciences. With the benefit of hindsight and the passing of time some insights have emerged about the tensions I felt whilst conducting empirical research, seeking concrete conclusions within a broadly post-modern philosophical frame. I positioned this study as complex realist, noting that whilst I was not seeking to represent a fixed external reality, lived realities (though they are complex to unearth) could be better understood. When asked at *viva voce* how I reconciled my complex realist approach with the consensus that complexity is broadly conceived in postmodern terms (see Davis and Sumara, 2006; Cilliers, 1998) my response was that I can't reconcile it but may just have to live with it. The study was postmodern in the sense that one can never claim complete knowledge of any social object; social systems are historically contingent, contextually unique and temporally probabilistic. The act of representing the social world reveals that it is no longer what we assumed it to be, because representations lead to actions which affect the 'world' and change it. Davis and Sumara discuss this using the concept of simultaneity between education and research; between representation and presentation. The world never stops coming into focus (Osberg, Biesta and Cilliers, 2008). At the same time however, as the researcher I rejected the radical relativity of social constructionism, maintaining that knowledge about social objects can be theorised and generalised to some extent, though perhaps not far beyond the research context. Complexity thinking, as the conceptual framing, and complex realism, as the ontological positioning are uncomfortable bedfellows to some extent. The postmodern flavour of complexity maintains its integrity in the social sciences at the level of philosophical discussion. However, in the realm of empirical social research, where learning something of the reality being researched is a pre-requisite, it falls short and (perhaps) must inevitably make concessions to some version of realism. Complex realism, to paraphrase Winston Churchill, may be the worst candidate, except for all the other candidates.

The learning narratives in this study illustrate the limitations (and the paradox) of attempting to derive credible, concrete insights about a complex social context using a complexity framing. My attempts to both embrace the complexity of small group classroom learning *and* extract epistemologically valid knowledge products about how it functioned led me to a middle ground from which I achieved elements of both, but the entirety of neither. Inevitably, the narratives were an attempt to impose aspects of realist research rigour onto a system resistant to reductive analysis (as per cautions from Newell, 2008 and others). One example of this was the decision to use verbal utterances as the basis of the social network analysis and to comment separately on some of the associated gestures and other non-verbal interactions. The primacy of verbal interaction is 'in-built' within the realist tradition of research using classroom transcriptions, and though an imperfect fit for complexity-framed research, it was something of a default when designing the research. In some ways my approach embraced complexity, whilst also being somewhat apologetic about the impossibility of positivist-style validity and repeatability.

When pursuing the concept of pupil salience in future research I look forward to wrestling with this epistemological conundrum by innovating in data collection and analysis and be less apologetic about the rich, situated nature of complexity-framed classroom research.

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APPENDICES

APPENDIX A

A Collection of Definitions of Complex Adaptive Systems from Sullivan (2009). The shaded sections at the bottom are my more recent additions to the list. My highlights indicate commonly recurring characteristics with applicability to classrooms. These were used to derive the CAS classroom definition presented in Chapter Three.

Author(s)	CAS definition
Bloch (2004)	- Open exchange - Networks - Phase transitions between chaos and order - Fitness peaks - Nonlinear dynamics - Attractors, bagels and emergence (A bagel is a torus attractor, where things keep going around and around, while never exactly repeating.)
Bloch (2005)	*Characteristics of complex adaptive entities:* - self-maintaining though their components, even shapes, may change - open - part of networks - parts or fractals of other entities - dynamic, experiencing phase transitions between chaos and order
Carr-Chellman (2000)	*Underlying concepts of the new science:* - perturbation (conscious creation of dissatisfaction - Self-organization (control of the whole is derived from the interactions of the whole) - Dissipation of Rigid Structures (hierarchies, patterns of interaction, etc) - Sensitivity to initial conditions (butterfly effect) contributes to our understanding of the limits of prediction - Entropy (managed short-term by the building of boundaries, but living systems require large dissipation of energy to maintain functions)

	- Bifurcations (turning points that are the result of perturbation) - Attractors
Clarke, Erickson, Collins & Phelan (2005)	*Features of complex learning systems from Davis & Sumara (2004):* - internal redundancy - internal diversity - neighbour interactions - decentralized control - enabling restraints
Clarke & Collins (2007)	*Characteristics of CAS:* - exhibit networked rather than hierarchal structures - feedback loops - capacity for self-organization or self-regulation - disequilibrium - nested nature (fractal character)
Collins (2004)	*Terms collected from Capra:* - disequilibrium - order and chaos - self-organization - ecology (D&S concept that knowledge and nature are not separate) - evolution - emergent properties (synergy)
Davis & Simmt (2006)	*List of qualities necessary for a complex learning system:* - self-organizing - relationships tend to be short range - bottom up emergent - exhibits transcendent properties not manifest in individual agents - embody their histories - complex forms are often nested, with forms distinguished according to group size and evolutionary pace (drawn out in figure 1 on p. 296)

	Conditions necessary "for the emergence of co-activity that might give rise to previously unrealized orders of organization" (p. 309) - internal diversity - internal redundancy - decentralized control ("is only possible if the phenomenon is framed by constraints that enable unanticipated possibilities. Complex systems are rule-bound, but those rules determine only the boundaries of activity, not the limits of possibility" (p. 311)) [strange attractor?] - enabling constraints - neighbor interactions (these neighbours are not people but ideas; must be sufficient density)
Davis & Sumara (1997)	*Distinguishing characteristics of complex systems (from Waldrop (1992):* - capacity to undergo spontaneous self-organization - adaptive - more than the sum of it's parts, it learns.
Davis & Sumara (2001)	*These are cobbled together from throughout the paper, and not presented as a definition:* - self-organizing - nested - transcend their components - adaptable, dynamic and robust
Davis & Sumara (2006)	*Necessary qualities to be classified as complex*: - self-organized - bottom-up emergent - short-range relationships - nested structure (aka scale free networks) - ambiguously bounded (open) - organizationally closed - structure determined (can change their own structures; embody their histories; "they learn - and are thus better described in terms of Darwinian evolution than Newtonian
Doll (1989)	*An admittedly partial list that represents what he was trying to do in this particular classroom:*

	- boundaries / attractor area - self organization - occurs suddenly and spontaneously - occurs only when there is a difficulty to overcome (Piaget called this "disequilibrium") - there are bifurcation points - critical junctures when re-organization occurs.
Gilstrap (2005)	*good complex adaptive systems:* - open - organic - nonlinear - self-referencing - have strange attractors
Harkema (2003)	*Characteristics of CAS:* - nonlinearity - dynamic behaviour - emergence and self-organization
Livneh & Parker (2005)	*Chaotic complex systems are:* - nonlinear attractors (fixed point, limited cycle, and strange) - dynamic open dissipative stability - bifurcation - chaotic period - new, more complex order - self organizing - self-similar (related to fractals)
Mennin (2006)	*Characteristics of CAS:* - agents - self-organization - nonlinear

	- interconnected - far from equilibrium - self similarity [like some fractals] - co-evolution - control parameter - phase space [I think this and the previous are just set ups for] - attractor
Nelson (2004)	*Holland's Model:* - Four properties - aggregation - nonlinearity - flows (of information) - diversity - Three mechanisms - tagging - internal models (develop from interactions through) - reproduction through fitness - recombination through cross-over - replacement - building blocks [small # of inputs, when combined, make many possibilities - aka DNA]
Pines (1998)	*Complex adaptive systems can be regarded as a collection of information gathering entities (agents) which:* 1) Respond to the environment 2) Respond to one another 3) Segregate information from random noise 4) Compress regularities into a model 5) Modify their internal characteristics—i.e., adapt to improve their performance of desired tasks Typically, complex adaptive systems: 6) Possess intrinsic nonlinearities which can lead to either negative or positive feedback

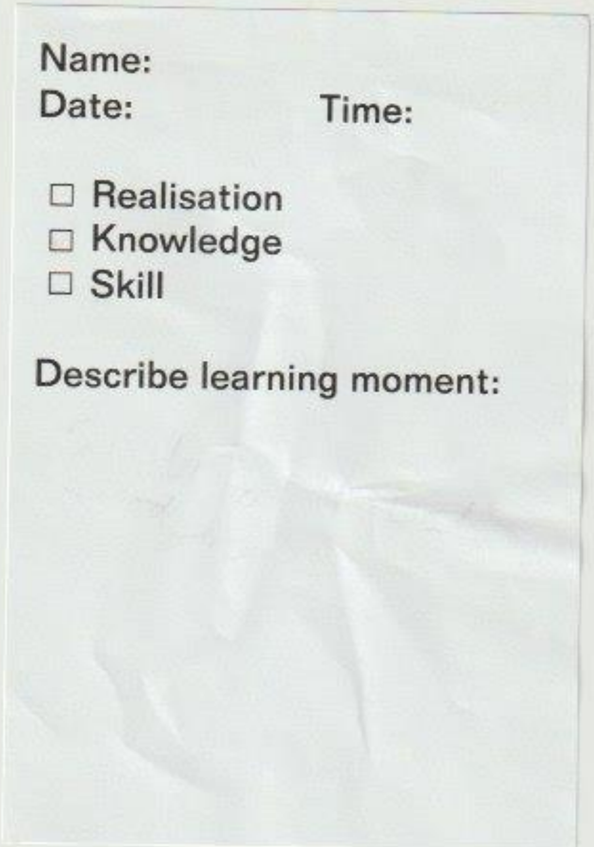
	7) Display emergent (self-organized) behaviour 8) Are unusually sensitive to initial conditions 9) Are rarely capable of finding an optimal state; instead, get "stuck" in local minima. 10) Finally, intervention in the affairs or behaviour of a complex adaptive system often gives rise to unexpected consequences
Polite (1994)	*Blair's theoretical concepts associated with chaos theory in educational systems:* - butterfly effect - onset of turbulence - dissipative structures - strange attractors - recursive symmetries (feedback)
Robinson (2005)	*Includes the following elements, though they are not organized as a definition or as elements of a CAS:* - emergent properties - self-organization - sensitivity to inital conditions (butterfly effect) - fitness peaks - In my opinion, he describes a kind of strange attractor effect "during the life of the organism every cell undergoes a change (i.e., a molecular turnover) even though the organism itself remains stable. . . Organisms are dynamic fields" (p. 173)
Sinclair (2004)	*Citing Kelly (1994) "complex systems are adaptable, evolvable, resilient, boundless, and novel" (p. 69)* *From Davis & Simmt (2003) Necessary but insufficient conditions to be capable of innovation:* - internal diversity - redundancy - decentralized control - organized randomness - neighbour interactions
Smitherman (2005)	*CAS definition*

	- cellular autonoma (independent parts following simple rules) - dissipative structures - Autopoiesis / openness
Sullivan (2009)	Well-networked Nonlinear Bounded Synergistic (emergent patterns aggregate across levels of the system)
Hardman (2015)	*Points out that the indeterminate nature of complex systems makes them difficult to model, but presents the following to differentiate complex systems from chaotic systems:* Determined by iterations or algorithms acting locally upon multiple elements. Influenced and driven by the environment. Indeterminate, with the history of the system being important. Semi-stable structures may 'emerge' which are capable of self-organisation and response to environment.
Carmichael & Hadzikadic (2019)	*Characterize a general CAS model as having a significant number of self-similar agents that:* •Utilize one or more levels of feedback; •Exhibit emergent properties and self-organization; •Produce non-linear dynamic behaviour.
Preiser *et al.*, (2018)	*Six principles for defining CASs:* CAS are constituted relationally CAS have adaptive capacities Dynamic processes generate CAS behaviour CAS are radically open CAS are contextually determined Novel qualities emerge through complex causality

**(NB these sources refer to CAS characteristics across multiple fields, not exclusively education)*

APPENDIX B

Example of Moment of Learning (MoL) post-it note.



Name:

Date: Time:

- ☐ Realisation
- ☐ Knowledge
- ☐ Skill

Describe learning moment:

APPENDIX C

Whole class MoL data for the whole research week

Learning Type	Frequency				Total
	Monday	Tuesday	Wednesday	Thursday	
Realisation	**22**	**13** (2)	**20** (1)	**8** (1)	**63** (4)
Realisation + Knowledge	*3*	*2*	*0*	*0*	*5*
Realisation + Skill	*0*	*0*	*0*	*0*	*0*
Knowledge	**10**	**27** (4)	**11** (3)	**20** (2)	**68** (9)
Knowledge + Skill	*0*	*0*	*1*	*0*	*1*
Skill	**2**	**4**	**0**	**8** (4)	**14** (4)
Metacognitive	*4*	*5*	*2*	*8*	*19*
Misc / Erroneous	**2**	**4**	**0**	**1**	**7**
TOTAL	**36**	**48** (6)	**31** (4)	**37** (7)	**152** (17)

Parenthesis indicate that I adjusted the category of learning designated by the pupil.

APPENDIX D

Example of researcher field notes.

Monday 17th June 2019

•<u>Complex Adaptive System</u>

o Influence of disruption on atmosphere and focus.

o Unhappiness from one P about their group. Evidence of impact emotion / mood / self-control has on learning atmosphere.

o Mixture of small group (discussion and decision making) and whole class (feedback and elicitation) formats.

o See observation re. activity, autonomy, cooperation and learning.

o A consequence of 'edge of chaos' style activity is that learning moments do not occur sequentially, but more randomly. Then they must be linked and connected coherently through Q-ing and distilling activities. Ps do make discoveries and realisations through autonomous activity but require support deriving and articulating specific learning from them. Autonomous learning moments have a certain practical, goal-orientated utility in that they guide immediate and subsequent practical (trial and error) actions towards the goal (e.g. adjusting the amount of water in the bottle). However, for transfer of learning and learning which is not contextually situated a T in the structuring role is useful.

o Over lunch R and T decided that it would be productive to create an activity to draw learning together in groups. T designed a worksheet which leads each team through thinking about their options and their choices, including justifying and explaining. This was a judgement about the need to impose structure on the autonomy.

o Factors influencing learning: Concentration, social, behaviour (focus, impulsiveness, equal contribution), cognitive ability (draw conclusions), articulacy, weather (it was windy). First-order / second-order factors?

o The question might be, why isn't a class like a CAS? What prevents it?

•<u>Moments of learning</u>

o Huddle 1: Ps drawing substantially on existing knowledge and experience. Lots of talk about mentos and diet coke and imagining ways of applying that reaction to the pump system. Linking to what they know.

o Ps suggesting different roles within each group, e.g. designers, researchers, measurers etc.

o Vignette:

Groups testing different bottles using the launcher, determining which bottles are best or go furthest. Conclusions tending to be about which bottle is best based on which goes furthest. T – arrives and begins to Q Ps about why they are doing what they are doing (putting paper inside bottles). T- 'how can you be sure that your measurements are accurate?' 'OK, just pause for a moment….' T asking Qs about keeping variables the same to make testing fair. Eliciting explanation. T applies structure to pupils exploration and guides thinking towards key questions. This is a steering role, an injection of structure, scaffold. T – capitalises on what the children bring, try out, suggest. Like a craftsman shaping a raw material.

o Mixture of trial, research, procedural, practical, patient, impatient, paper-based and hands-on.

o Huddle 3: T helps Ps to distil learning. Helping them get from what they observed to what they learned from it.

o Question - Is learning taking place when the T is not present?

• My positionality / influence

o Children excited by project, a few came to greet me with Qs.

o Had to reprimand one child for calling me Mr Ben.

o Have been drawn into T mode several times with both learning, procedural and behavioural incidents. This is a consequence of my moral commitment to learning and my sense of responsibility to the smooth running of the activity and to support the T.

o

•<u>Procedural (including adaptations)</u>

o Switched to just one filming table for ease and accuracy of playback. Groups to take it in turns to sit there and be filmed.

o Threat – P not wanting to fill in learning moment post-its because they're so absorbed in the task. This is a challenge to the learning wall procedure. Instigated designated learning moment times, before transitions (e.g. break/lunch/home time). Metacognitive insights do not emerge naturally, they are effortful. (Discuss this).

o Some technical issues with recording equipment. Batteries, connection etc.

o Analysis Idea – as week progresses, look for threads running through individual's post-it notes showing learning building upon learning.

•<u>Other</u>

o Initial introduction and demonstration of a dry bottle being fired. Children answered Qs and made suggestions and predictions about what would happen and why. Observing, some discussion. T - Qs to elicit thinking and responses.

o Huddle 1: T- What will we need to find out? Children making suggestions.

o Suggestions about: ways of working, things to do, ways of using T as a resource, how will they achieve goals, resources? What will Ps need from one another? Ps suggest: support, resilience, sharing, collaborating.

o T – eliciting ideas from Ps.

o T – what do you need from me this morning?

o Burst of excitement and 'chaos' this morning. T instinctively wants to impose some order and structure on the chaos. Definitely 'edge of chaos'. This will gradually calm down during the week as the novelty wears off and T makes decisions about when and how to impose structure on the activity. This is something that the teacher brings to learning. Experience of helpful structures for thinking and action in the interest of learning. Ts know that free exploration alone will not capture productive learning.

o Ps using the mathematical terminology to describe what they did 'we used 200ml and a 60 degree angle….'

o Observation – relationship between activity, autonomy, cooperation and learning. The more autonomous the learning and activity, the more social relationships and degrees of peer cooperation mediate learning. If learning arises from activity then the more cooperative the activity the greater likelihood of learning arising.

o The children are not used to independent activity. Monday morning showed this to an extent. Factors like self-control, peer cooperation, planning etc did obstruct learning to an extent.

o T provided resources for the Ps in the afternoon. Visited each group, elicited learning.

•<u>Review of day with Tom:</u>

o Start Tuesday by sharing some learning and review learning wall process.

o Reminder about learning types: that realisation refers to 'why' and 'how' things happen.

o Consider taking some groups to empty space for recordings.

o Possibly interview a few children as a pilot.

APPENDIX E

Example transcript from individual pupil interview. (Not used for analysis)

Interview 10 Pupil 26 Thurs

(Question 1)

1. **Researcher:** Just to get you warmed up, tell me what's your favourite thing about your bedroom at home?

2. **Respondent:** Um I like my unicorns on my wall because I have like a desk and then I have unicorns on them.

3. **Researcher:** Okay.

4. **Respondent:** And I've got my unicorn piggy bank and stars that glow up in the night.

5. **Researcher:** Oh really? Okay, so you're into unicorns then? How many have you got?

6. **Respondent:** Um five.

7. **Researcher:** Five? Wow. Are they hard plasticky ones or are they soft squishy ones?

8. **Respondent:** Um three, oh no, I've got six I think. I have one squishy one.

9. **Researcher:** Yeah.

10. **Respondent:** Three hard ones that are made out of glass.

11. **Researcher:** Yeah.

12. **Respondent:** And one that's like a teddy.

(Question 2)

13. **Researcher:** Oh nice, okay. Wow. Do you share your bedroom with anybody, or is it just your own?

14. **Respondent:** No, I just share it with my.

15. **Researcher:** You share it with yourself?

16. **Respondent:** Yeah.

(Question 3)

17. **Researcher:** Brilliant. Oh that's very nice. Today's our fourth day on the rocket project, how are you finding it so fa?

18. **Respondent:** I like it because I'm getting very, a lot of like um facts about rockets that I didn't know about.

19. **Researcher:** Oh okay.

20. **Respondent:** And I kind of wanted to like learn about rockets and how the space works and stuff.

(Question 4)

21. **Researcher:** Interesting, okay. Are there any particular things that you've done that you've enjoyed?

22. **Respondent:** I liked doing the water and the weighings when we were trying them in the playground.

(Question 5)

23. **Researcher:** Right yeah, okay, testing out water and wings. Good stuff. Okay. Do you want to read that out to me? That's what we're going to talk about.

24. **Respondent:** I realised that the three wings is more aerodynamic than having four wings. I realised this because my friend told me.

(Question 6)

25. **Researcher:** Right. So this is one of those moments where you learn something from somebody else. Just describe for me what was happening at the point when you learnt that?

26. **Respondent:** Um well we were deciding if we should do three or four wings and then when we went outside to do things in the playground we brought an extra wing so we did the three wings and it went slightly not as far because it was spinning a lot. No, the three wings was kind of like normal, and when it was gliding it was just staying still in the air. But the four ones, because I think that one of the wings was slightly smaller than the rest.

27. **Researcher:** Okay.

28. **Respondent:** And when it was in the air it was kind of like spinning a lot and then it fell down.

(Question 7)

29. **Researcher:** Right. So it was partly that your friend told you but also you saw it happen as well. Okay. And who else was there?

30. **Respondent:** I was on my own then because **** and *** were at choir.

31. **Researcher:** Oh I see, oh okay, so you were just testing the rocket yourself. So who was it that told you that then?

32. **Respondent:** I just, oh um when **** got back I told her all of it and then she said yeah, because three wings were more aerodynamic than four.

(Question 8)

33. **Researcher:** Oh okay. Oh great, so that was kind of like a team effort, wasn't it? What did it feel like when you learnt that?

34. **Respondent:** Um I felt kind of happy because then when I'm like older and when we go to a different school and if we ever learn about that and do rockets again I'll have that knowledge, so when we do that I will remember what to do.

(Question 9)

35. **Researcher:** Mm, okay, good stuff. Did you know anything about this topic before we started it this week?

36. **Respondent:** Mm well I kind of knew a bit about space, not just much of rockets.

37. **Researcher:** Did you? Okay. Anything about things flying or aerodynamics or anything like that?

38. **Respondent:** No. I didn't even know what aerodynamic means.

39. **Researcher:** Oh really? But you do now, don't you?

40. **Respondent:** Yeah.

(Question 10)

41. **Researcher:** Oh okay, good stuff. Have you ever been on a plane?

42. **Respondent:** Yes.

43. **Researcher:** Have you? Where have you been to?

44. **Respondent:** Um I've been to Gran Canaria and I've been to Center Parcs.

45. **Researcher:** Oh nice.

46. **Respondent:** And soon I'm going to be going to Turkey.

(Question 11)

47. **Researcher:** Oh lovely, oh that's really nice, isn't it? Okay. So you realised that bit of learning when you were outside testing?

48. **Respondent:** Mm-hm.

49. **Researcher:** Okay. And then when you came back in you spoke to Abby and she sort of explained the fact that supported what you'd seen, I suppose?

50. **Respondent:** Yeah.

(Question 12)

51. **Researcher:** So it was a bit of a team effort, wasn't it? How do you think you might be able to use that new knowledge you've got?

52. **Respondent:** Um maybe if we do something like this again, like when we do it now, maybe next year we might be making them again to see what our knowledge was.

53. **Researcher:** Okay.

54. **Respondent:** About anything we remembered and what we know about them, and then we might be shooting them off again, so I'd know what to do.

(Question 13)

55. **Researcher:** Oh okay, good stuff. Right then, so last couple of questions then. Can you complete this sentence: I tend to learn best when…

56. **Respondent:** Um when I'm outside.

57. **Researcher:** Tell me why?

58. **Respondent:** Well when I'm outside I'm more concentrate because sometimes when I'm inside, where there's like closed doors you can hear everything and all the different years, but when you're outside there's no walls, so all the sound doesn't get trapped in the walls.

59. **Researcher:** Oh, okay. So what's the problem with having noise around you?

60. **Respondent:** Well normally at home or when I'm at a party I get frustrated when I hear lots of noises because it gives me kind of a bit like frustrated because sometimes it's like everyone's all around you and they're all screaming and shouting and it's all in your ears.

(Question 14)

61. **Researcher:** Okay. See if you can complete this sentence then: things which prevent me from learning are…

62. **Respondent:** What does prevent mean?

63. **Researcher:** It means stop you, things which stop you from learning.

64. **Respondent:** Oh. Um people distracting me.

65. **Researcher:** Mm-hm.

66. **Respondent:** People talking, whispering, and when people try to talk to me but when I try to ignore them.

67. **Researcher:** Okay, good. Right, you've done very well there. Thank you very much, I'm going to stop that.

APPENDIX F

Voluntary Informed Consent form from Teacher

Critical Moments in Learning Project

Dear [redacted]

During this project week the pupils will undertake a variety of learning activities helping them work towards an end goal as a class. They will make a range of decisions about how, where and with whom they participate. They will be supported in identifying moments in their learning through the week asked to record these in the way we have discussed. Everything will be explained to them thoroughly and they will have the chance to ask as many questions as they like.

You are agreeing to help plan the research week of activities, to lead the learning through the week (in your capacity as class teacher), to keep a daily journal of your noticings about the pupils' learning and to support pupils in carrying out the reflective tasks through the week and to have this data analysed by me as part of the research. You are also consenting to the possibility of being captured on film during the week.

Teacher Consent Form

On the basis of having read the information document and having met with the researcher Ben Knight and discussed the research thoroughly, I consent to participate in this doctoral study.

Name .....[redacted].. Date ...21 - 06 - 19

Signature ....[redacted]..............................

APPENDIX G

Parental consent form.

[redacted]

Dear parents of Year 4,

My name is Ben Knight and I am a senior Lecturer in education at [redacted]. I was a primary teacher in Bristol for 11 years and now teach student teachers, some of whom come to [redacted] Primary School on placement.

In the summer term I will be will be undertaking a one week research project with year 4 as part of my doctorate. The children will be spending the week beginning Monday 10th of June working on a collaborative class project and I will be documenting moments in which learning emerges in an attempt to gain a better understanding of exactly how, when and why learning occurs. Developing new insights into learning will be interesting and fun for the children as well as useful for teachers and my colleagues at [redacted].

I will be documenting moments of learning by capturing video footage of the class during project work and by interviewing a small handful of individual children.

Video footage:
The video footage will be a mixture of whole class wide shots and narrower group shots. The purpose of the video is to capture evidence of how pupils network and interact with one another during lessons. Footage will be stored securely on the [redacted] computer drive, only viewed by myself, the class teacher and possibly my doctoral supervisors and examiners. Footage will not be available for anyone else to view, search for or come across accidentally. The video footage itself is not the research data, it is merely a tool to help me analyse the learning in detail without having to capture everything live as it happens. Footage will only be kept for as long as necessary to analyse and transcribe extracts of learning dialogue between pupils, no longer than the final thesis submission date in early 2021. As a teacher educator and a primary school teacher of many years I understand parental concerns around filming of pupils in school. Please rest assured that footage will be treated with the utmost sensitivity, privacy and confidentiality and be held on a secure [redacted] Drive. Safeguarding of pupils is top of my priorities and I will be working closely with the school to ensure this remains the case throughout the process.

Interviews:
In addition to the whole class documenting of learning, I plan to interview a small handful of pupils about their learning during the project week. The questions will ask them to reflect on their activities and moments in which they learned particular things. I am interested in

their descriptions of these instances. These pupils will be selected during the project week based on the instances of learning which they report. Interviews will take place on the Friday at the end of the week and will last about 20 minutes. Pupils who are interviewed will not miss out on crucial learning opportunities or playtime as a result of participating. If you wish to see a copy of the questions please email me on the address given at the end of this letter. The interviews will be voice recorded and held on the secure [redacted] Drive for the purposes of analysis. Recordings will be deleted after the thesis submission point in early 2021 at the latest. I am an experienced teacher and academic and have an enhanced DBS clearance for working with children.

The week of project work will be enjoyable and interesting for the children and the research methods for documenting learning will be as unobtrusive as possible. Most of the time the children will be busy and productively occupied and not thinking about the video camera or my presence as a researcher. The insights offered by this research have the potential to teach us a great deal about learning processes which will be particularly useful to the school and to [redacted] as we prepare the next generation of teachers for the challenges of the primary classroom.

Your support and cooperation with this project is much appreciated. Kindly indicate below if you consent for your child to be captured in the filming and participate in the interview aspect of the research and return the slip to school. If you have further questions or require further information please feel free to email me directly on [redacted] or you can email my doctoral supervisor [redacted] on [redacted]. Should you have any concerns regarding the ethics of this research project you can contact the [redacted] Research Ethics committee on [redacted]

You have the right to withdraw your child from this study up to and including 31st July 2019.

Many thanks,

Ben Knight.

Please delete as appropriate...

I have read and understood the information above and **give consent** / **do not give consent** for my child .... to be captured on video footage for the purposes of the research as set out above.

In the event that my child ....is invited to be interviewed I **give consent** / **do not give consent** for this to happen as set out above.

Signed.. (parent/guardian)   Date ....

APPENDIX H

Pupil Consent (Assent) form.

Pupil consent form

Dear pupil, please tick the boxes if you agree with the statements and sign at the bottom if you consent to participate in the research project.

I understand what is involved for me in participating in this research project. ☑

The project has been explained to me. ☑

I understand what will be happening in class during the project week. ☑

I know what things will be recorded and how. ☑

I understand that I might be asked to participate in an interview at the end of the week. ☑

I have been informed about the purpose of this research project. ☑

I have had the opportunity to ask questions about the project. ☑

I understand that I can withdraw from participating in the research at any time during the project week or afterwards. ☑

I consent to participate in the research project ☑

I do not consent to participate in the research project ☐

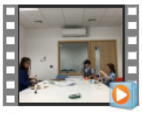
Signed [redacted] .... Date 21.05.16

APPENDIX I

Significance of utterance	**Examples from videoed episodes**
Insignificant	Talking to self or no-one in particular. Interactions between two group members about something unconnected to the task which no other members hear or listen to. Brief exchanges involving some or all group members about irrelevant topics which do not last long enough to influence proceedings. Attempts at subversion or humour which are ignored.
Significant (disruptive)	Arguments which grind productive interactions to a halt. Lengthy episodes of humour, diversion or subversion. Disputes over resources or roles which prevent members from carrying out tasks. Utterances where the goal is disruption, retribution, jostling for status, seeking social alliances or withdrawal.
Significant (constructive)	Utterances which change the course of decisions about tasks. Utterances which elicit ideas or contributions from other members. Responses to suggestions. Disagreement and discussion. Ideas which gather significant support Ideas which generate significant opposition. Organisational suggestions which improve group working practices.

APPENDIX J

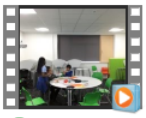
Group work episodes excluded from data analysis.



Wednesday(a) 3, 23, 7, 5, 1

1. Wednesday A (pupils: 3, 23, 7, 5, 1) 15 minutes duration.

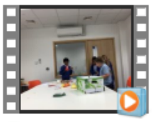
In this episode the five pupils are adapting their prototype rocket following a test launch. Pupils 1, 3 and 7 are responsible for 94% of utterances. Pupil 5 contributes most of the remaining 6%, with pupil 23 saying very little. Overall interactions are minimal and all procedural. The episode includes several periods in which no interactions occur at all.



Thurs(a) 9, 8, 30, 28

2. Thursday A (pupils: 9, 8, 30, 28) 21 minutes duration.

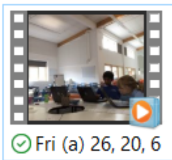
In this episode the pupils are modifying their prototype rocket. There are only a few short periods during which all group members are present. Pupils 9 and 28 in particular spend long periods away from or disengaged from the group. There are significant periods of silent, individual activity and silent shared activity (collaborating on a practical task without verbal interaction). Over 85% of interactions are procedural or miscellaneous. A significant proportion of interactions involve arguing over resources.



Thurs(b) 27, 2, 14, 21, 22

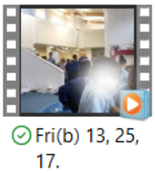
3. Thursday B (pupils: 27, 2, 14, 21, 22) 32 minutes duration.

In this episode the pupils talked over one another for significant periods making it difficult to determine and record interactions. Where interactions were sufficiently clear to record, they mostly concerned miscellaneous social topics. Only 3% of interactions were classified as concerning substantive subject knowledge. The pupils talked a lot, however there were no notable incidents of learning, potential, tangible or elaborated.



4. Friday A (pupils: 26, 20, 6) 13 minutes duration.

In this episode the three pupils worked on a laptop each for the entire duration and interactions were minimal.

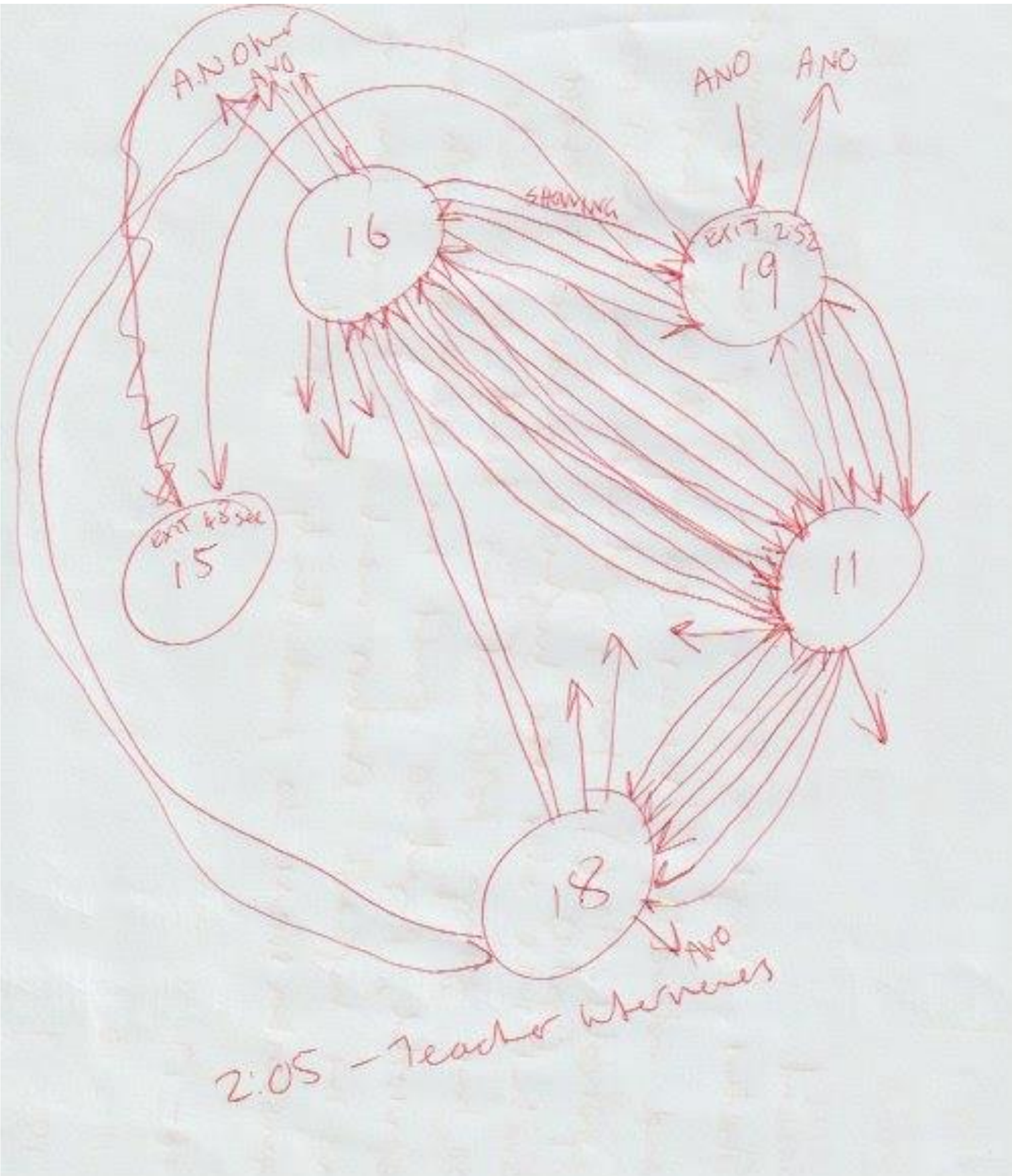


5. Friday B (pupils: 13, 25, 17) 3 minutes duration.

In this episode the three pupils begin by discussing ways of improving their rocket's performance but after 12 seconds pupils 13 and 17 depart leaving pupil 25 alone. No further interactions occur.

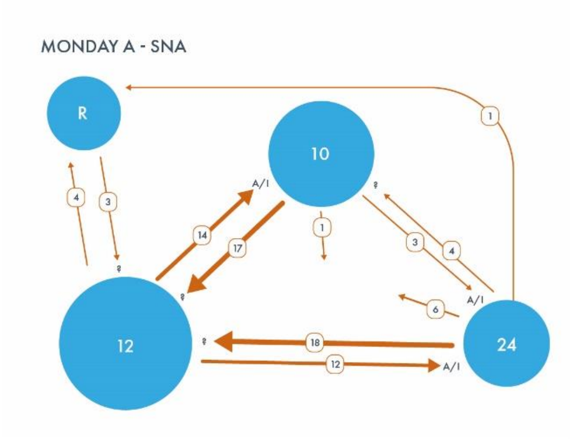
APPENDIX K

Example of initial pen on paper mapping of video episodes

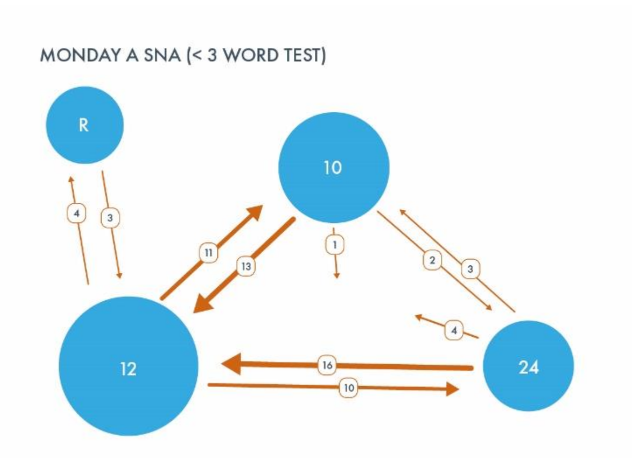


APPENDIX L

Sociograph of episode Monday (A) including and excluding utterances of fewer than three words.



Episode Monday A including all utterances.



Episode Monday A excluding utterances fewer than three words.

Excluding utterances fewer than three words did not affect the degree centrality of the episode. Overall interactive utterances were lower and net in-degrees did change slightly, however each pupil maintained his relative influence on the episode. The table below shows net in-degree for each pupil in both calculations.

	All utterances included	Utterances fewer than 3 words excluded
Pupil	Net in-degree	Net in-degree
12	+7	+7
10	-2	-1
24	-14	-11

This suggests that removing short utterances from the analysis would have little impact on degree centrality data. The effect would not be the same for each episode but having applied the ‘<3 word rule’ to this episode, I am satisfied that the length of utterance variable did not significantly skew the data. There were no examples across any episode of a pupil generating a significantly net + in-degree by repeated short utterances.

APPENDIX M

Glossary of key terms

This thesis contains a range of terms used in the context of complex systems. To aid the reader, I present the following definitions and explanations.

Term	Definition
Agents	Parts or components in a complex system. In human social systems agents can refer to individuals, but also features of the environment.
Ambiguously bound	Complex systems do not have crisp, clear boundaries. Neither are they fully open to their surroundings.
Birfurcation (or 'phase transition')	When sufficiently perturbed, a complex system can reach a tipping point and transform abruptly, sometimes dramatically.
Complexity Theory	A transdisciplinary theoretical framework, originating in the natural sciences, for conceptualising adaptation in dynamic, non-mechanistic systems.
Complexity Thinking	A heuristic often applied to complexity analysis in social contexts. Complexity thinking is a way of thinking which presumes that the world is complex. A way of seeing the world. It differs from 'hard' deterministic complexity science.
Complex Adaptive System	CASs are stubbornly resistant to definition (because of their inherent indeterminateness). A system which displays behaviours of complex self-organisation and emergence. Complex adaptive systems adapt of their own accord due to agent behaviours, rather than because of the influence of central authorities. CASs exhibit properties and behaviours not present in any of their individual agents.
Complex Realism	A synthesis of crucial realism and complexity theory. An ontology of complex realism posits that the social world is broadly probabilistic, but also sufficiently deterministic to impute causality to explanation social phenomenon.
Diversity	The range of differences between agents in a system, down to the micro level, which define possible responses. A great many diversities exist in any social grouping, however homogenously composed. This is different to demographic diversity in the political sense.

Edge of chaos	A transition space between order and disorder. Complex adaptive systems are characterised by their ability to avoid all-out chaos, though they are most productive in adaptation when at the edge of it.
Emergence	Phenomenon which arise bottom-up within a complex system, rather than being imposed from the top down. Occurrences ungoverned by central organising principles.
Enabling constraint	Structures imposed upon a social system to prevent it from becoming too open. This might mean constraining choices or resources for a collective.
Feedback loops	Positive and negative feedback is a characteristic of complex systems. Positive feedback amplifies the effect of a variable whereas negative feedback dampens it. Negative feedback operates like a thermostat. If the temperature drops too much it engages the boiler to raise it and when the temperature rises it disengages the boiler to make the temperature drop. Negative feedback helps maintain equilibrium. Positive feedback is seen when one change in a system produces other changes which encourage more of the original change. A balance between positive and negative feedback loops helps a CAS exist on the edge of chaos, without falling into chaos. Positive and negative in this sense do not equate to 'good' and 'bad'. Both are necessary prerequisites for a CAS. Classroom examples might include humour or anger from one pupil triggering humour/anger from others which feeds back to amplify the humour/anger in the original pupil and so on. The regulating presence of other pupils or the teacher might be the negative feedback in this scenario.
Nested	Systems enclosed within other systems, e.g. individual brains within, individual humans, within small groups, within the class, within the school, within the community etc
Non-linear / non-linearity	The many variables within a complex system are strongly interdependent meaning it is not easy to tell which inputs contributed to a given output. Causality is networked, not linear. This means the system responds differently to the same input depending on its current state and small changes can have large, unexpected effects whereas large changes may not result in dramatic change.
Recursion / recursive	Borrowed from mathematics and computer programming. Recurrence or repetition within a system. In social systems recursion refers to mutual co-adaptation/co-creation between agents in a system. In a classroom, individual pupils are changed by the collective, the collective is also changed by individuals.

Redundancy	A counterpoint to diversity. Redundancy denotes the presence of overlaps or surpluses of a given attribute or sameness within the system.
Self-organisation	Patterns of behaviour which emerge and aggregate across a complex system because of agent autonomy, not central control.
Short range relationships	Interactions between near neighbours within a system.

APPENDIX N

Institutional ethical clearance for the research project.

[redacted]

[redacted] REC REF No: ACE.19.02.019

14th March 2019

Ben Knight
[redacted]

Dear Ben

Application title: Learning as Emergence and Classroom as Complex System: A case study of a key stage 2 primary classroom

I am writing to confirm that the Faculty Research Ethics Committee are satisfied that you have addressed all the conditions relating to our previous letter sent on 5th March 2019 and the study has been given ethical approval to proceed with two recommendations.

1) *That Ben considers how he transfers his data securely from the school site to the* place where he can upload it to the [redacted] OneDrive.

2) He keeps the data for a longer period than only until he submits his thesis if he intends to publish from the data and also given examiners may make suggestions which involve returning to the data.

Please note that any information sheets and consent forms should have the [redacted] logo. Further guidance is available on the web: https://intranet.uwe.ac.uk/tasks-guides/Guide/writing-and-creating-documents-in-the-uwe-bristol-brand

The following standard conditions also apply to all research given ethical approval by a [redacted] Research Ethics Committee:

1. You must notify the relevant [redacted] Research Ethics Committee in advance if you wish to make significant amendments to the original application: these include any changes to the study protocol which have an ethical dimension. Please note that any changes approved by an external research ethics committee must also be communicated to the relevant [redacted] committee.
http://www1.uwe.ac.uk/research/researchethics/applyingforapproval.aspx

2. You must notify the University Research Ethics Committee if you terminate your research before completion;

3. You must notify the University Research Ethics Committee if there are any serious events or developments in the research that have an ethical dimension.

The Faculty and University Research Ethics Committees (FRECs and UREC) are here to advise researchers on the ethical conduct of research projects and to approve projects that meet [redacted] ethical standards. Please note that we are unable to give advice in relation to legal issues, including health and safety, privacy or data protection (including GDPR) compliance. Whilst we will use our best endeavours to identify and notify you of any obvious legal issues that arise in an application, the lead researcher remains responsible for ensuring that the project complies with [redacted] policies, and with relevant legislation. If you need help with legal issues please contact [redacted] (for Health and Safety advice), [redacted] (for data protection, GDPR and privacy advice).

Please note: The UREC is required to monitor and audit the ethical conduct of research involving human participants, data and tissue conducted by academic staff, students and researchers. Your project may be selected for audit from the research projects submitted to and approved by the UREC and its committees.

We wish you well with your research.

Yours sincerely

[redacted]

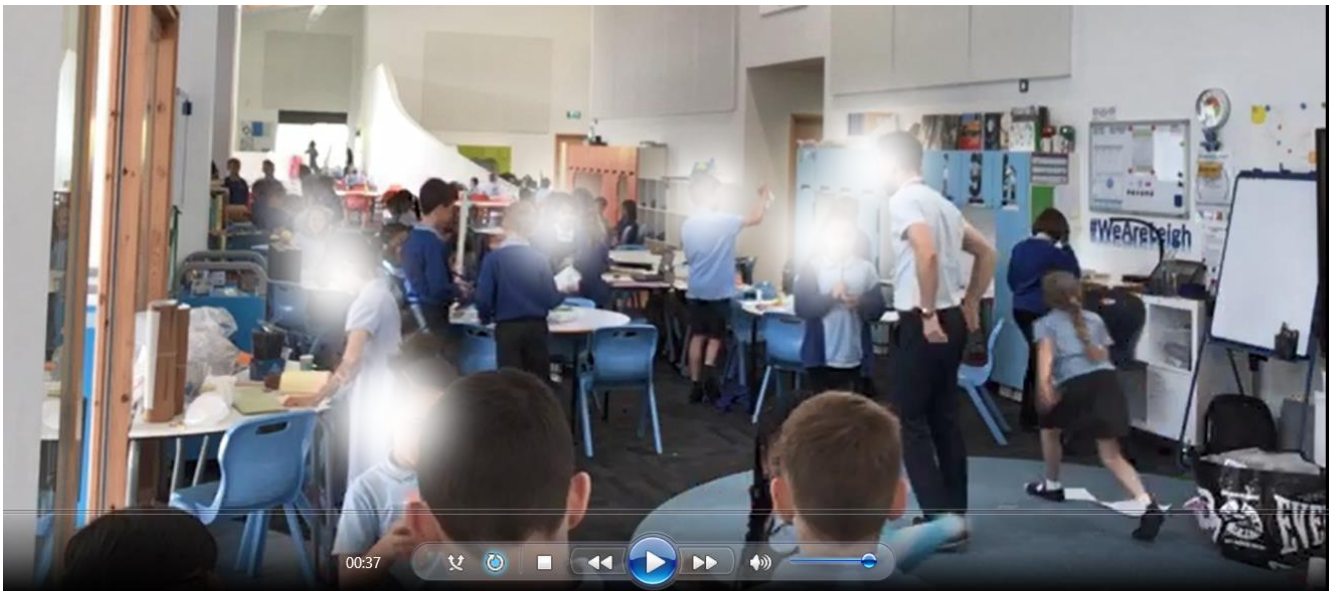
[redacted]
Chair Faculty of Arts, Creative Industries & Education
Research Ethics Committee

c.c. [redacted]

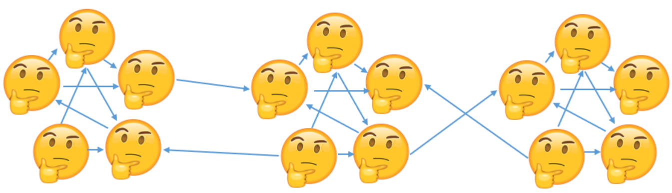
APPENDIX O

Brief overview of classroom activities during the research week. Drawn-up by the teacher prior to commencing the project. Image to illustrate open-plan blue 'class zone' space and slide from Monday introduction explaining decentralised group work structure.

	Mon	**Tues**	**Weds**	**Thurs**	**Fri**
AM	Intro to project Group work expectations Demonstration of rocket launch Split into teams Begin research – what will we need to do? Posing Qs	Morning briefing / recap Make requested resources available to groups Chdn to start experimenting – what does/doesn't work and why?	Morning briefing / recap Free flow group activities – working on prototypes	Morning briefing / recap Group working – bottle/nose/wings/weight	Test morning and final tweaks Finalise presentations ready for the afternoon
PM	Continue research Write plan of action for Tues Chdn to request resources for following day	Working in teams Sharing breakthroughs Launchers available outside for testing prototypes Write plan of action for Weds Chdn to request resources for following day	Whole class hand held testing? What have we learned about aerodynamics and nosecones? Continue group activities Write plan of action for Thurs Chdn to request resources for following day	Briefing / recap / looking ahead to Friday Continue working in teams Begin work on ppt presentations	Fly final rockets!? Groups make presentations about their rocket design processes and launch outcomes



But remember, you will be working…



…within teams

AND

…between teams.

Share information, be collaborative and help each other out!