Stories of Science

An auto/biographical study in primary science

by

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Abstract

This auto/biographical study examines a current dominant narrative within primary science. This concerns the often-reported connexion between subject knowledge and the impact this has on teacher confidence and consequently to pupils' attitudes to science and to the pipeline of potential future scientists. A detailed analysis of the primary science literature and reports such as Wellcome Trust (2017) has questioned this link.

Using an auto/biographical approach enabled me to utilise the personal narratives of successful science educators by listening to, and discussing with them, their life stories of science. These stories demonstrated their understanding of effective primary science teaching. Importantly, differences emerged, which related to individual understandings of the nature of science. Consequently, teachers who receive advice from these educators are provided with diverse interpretations of effective science teaching.

Hearing these stories led me to also question my own beliefs of science, particularly how knowledge is created and shared. I undertook this development using Living theory as a frame. (Whitehead, 1987). As a result, two models were created to support the analysis; the first dealt with the classification of knowledge, a Horizontal and Vertical Structure of knowledge (HVSK) and the second focused on knowledge construction, the Sphere of Knowledge Construction (SKC).

The recommendations from this thesis apply equally to qualified teachers and those training to be teachers. Firstly, models of knowledge classification should be used to discuss individual knowledge creation in initial and continuing teacher education. Secondly, stories of the sciences should play a central role in understanding the problems and the challenges that are inherent in the creation of understanding. Thirdly, opportunities should be provided for teachers and student teachers to be supported in science by significant others through practitioner-expert communities. Fourthly, research should be carried out into approaches that provide access to the stories of science without enforcing a science worldview.

Contents

Introduction

This introduction combines an outline of each chapter alongside a justification for both the methodology selected and the material collected. The introduction also identifies some of the changes that have taken place in my thinking during the period of study. I begin by explaining the aims for this work before discussing the structure of each chapter.

0.1 Context of the study

This study aimed to examine how successful science educators' understanding of primary science education contributes to and influences their educational practice. The phenomena investigated are the thought processes, and practices, of successful science educators expressed through narratives of their lives and professional work. (See chapter 5, section 5.2.2 for a discussion of the definition of successful science educators and the method of selection). The unique contribution that this work brings is the opportunity to use successful science educators' stories to examine one of the current dominant narratives of primary science from within the perspective of a narrative research position. This approach recognises narratives as a way of knowing, for narratives are how humans understand and develop meaning (Bruner, 1986; Bruner, 1996; Bruner, 2002; Hendry, 2010; and Nielsen, 2010), I will also 'knock aside some oft-made, simple, or stereotypical, assumptions about there being a fundamental opposition between narrative and science' (Morgan and Norton Wise, 2017, p 1). Narrative in science can create coherence between different viewpoints and theories whilst also playing a role in making science understandable for others.

The dominant narrative discussed in this work can be defined as one focused on the poor self-efficacy of teachers and their confidence to perform, also referred in this work as the paradigm (see section 0.2). The larger narrative, within which this work is situated, is the neo-liberal argument of science for economic growth (The Royal Society, 2010; DfE, 2013; The Royal Society, 2014; CBI, 2015). Within this dominant narrative are local narratives detailing personal and professional attitudes towards primary science teaching. These personal attitudes are found to influence professional attitudes and vice versa (van Aalderen-Smeets, Walma van der Molen and Asma, 2012; van Aaldereen- Smeet and Walma van der Molen, 2013). Attitudes are multi-dimensional and are influenced by the practicalities of context, including support, resources and time.

The definition of successful primary science varies with *Successful Science* identifying practical science lessons and the development of the skills of scientific enquiry (Ofsted, 2011); and time, expertise and resources which lead to outstanding lessons are suggested by the Wellcome Trust

(2017). The Primary Science Teaching Trust (2018) do not have a definition but state that what is needed is good teaching which requires the teacher to be at the centre of all they do.

The term successful science educator is defined in this work as those who have a national profile and influence primary science and the national primary science agenda. The narratives of these successful science educators are important because of the influence they have upon primary teachers, through continuing professional development (CPD), the development of curricular materials, and, indeed, the role some have played in the construction of the curriculum itself.

0.2 The current paradigm

This study began with a reflection upon the apparent cause and effect relationship between primary teachers' science subject expertise (X) and the supposed lack of children's interest in science (Y). The relationship takes poor pupil attitudes to school science (The Royal Society, 2010; The Royal Society, 2014; The Royal Society of Chemistry, 2014) and links this with teacher expertise in a very deterministic direct way by suggesting that it is a lack of X (subject expertise) that is the cause of Y (pupils' poor perception of science), X however also causes limited teacher confidence (Harlen and Holroyd, 1997) which also leads to Y. But the puzzle is, why does this relationship appear unchanging regardless of the qualifications and training provided for teachers during the four decades since HMI (1978) first raised the issue?

The term paradigm was made famous by Kuhn (1962), although throughout this work, I use Hacking's definition of paradigm which is the accepted way of solving a problem (Hacking, 1981). The accepted way of solving the problem in primary science has been to communicate the dominant narrative that the teachers lack expertise which ultimately results in fewer scientists. This dominant narrative is framed within a teacher deficit model, familiar in science education research at both the primary phase (Osborne and Simon, 1996; Harlen and Holroyd, 1997; Murphy and Beggs, 2002; Beggs and Murphy 2005) and secondary phase (Roberts, 1988; Fensham, 1988). The primary research documents are influential, with hundreds of citations that continually reinforce this deficit and even influence education reform (Oates, 2011). However, understanding the apparent failure of primary science teaching requires a deeper understanding of the problem. Alsop and Heinsohn (2005, p.4) identified that 'too often in education research there is a tendency to fixate on weakness' – in this case, the weakness of the primary school teachers.

0.3 The research questions

In this work I set out to examine:

- To what extent is the paradigm for primary science accurate, that states poor teacher subject knowledge and confidence leads to poor pupil perceptions of science, and how is primary science understood in the literature and reports?
- What contribution can auto/biographical narrative enquiry make to illuminating problems and or possibilities for primary science by engaging with the lived experiences of a sample of primary science educators, with reference to their own learning lives?
- What might be the implications of the above for teacher education and primary science, including the initial preparation but also CPD of science teachers?

After undertaking this study, I suggest that the key to understanding primary science education is not to be found in isolation in the classrooms, but instead in schools, policies and society, which extend far beyond the scope of a single teacher (Nespor, 1987).

0.4 Structure of the chapters

Throughout this work I will use the term the sciences (Feyerabend, 1993; Kind and Osborne, 2017) to signify that the current practices in ecology, cosmology, physics and nanoscience, astronomy, chemistry, geology, metallurgy, zoology, botany, genetics, palaeontology, molecular biology, physiology psychology, sociology or anthropology to name some branches of the sciences that all follow different approaches and investigate components of the known and unknown world. I hope to demonstrate that there is no incommensurability between the sciences and other ways of knowing.

Chapter 1 provides the context for much that follows and as I started this work as a naïve realist the journey examining my own understanding has been long and difficult. The chapter introduces 'the importance of the uniqueness of each individual's living educational theory (Whitehead, 1989) in improving practice and generating knowledge'. (Whitehead, 2008, p.103). The chapter is autobiographical and was included because there is no such thing as an objective observer (Heisenberg, 1924; Cassidy, 2001). I came to realise that there are many kinds of science as well as reasons that people use to explain the construct of scientific realism, and that the sciences are not as straightforward as I once assumed.

Epistemology, or the theory and relationship of knowledge and belief, has been a major personal challenge within this work. In this Introduction it should be noted that my educational view now is enmeshed with numerous stances. One is Gadamer' s (2004) view of knowledge, where humans cannot ever be completely aware of all that influences their understanding of the world, and results in a restricted 'horizon' (Gadamer, 2004, p.301) rather than a view of reality itself. The view from where I am currently (Nagel, 1989) is different from the view when the study commenced. I end the work as a critical realist and Chapter 1 explains my current position and identifies the path of travel recognising that in order to gain any understanding, 'leaving an individual or human perspective' (Nagel, 1986, p.7) behind is impossible. The rest of the thesis is an explanation of my *living theory* of science education and takes the reader down the tracks I have taken and is the story of my learning.

In chapter 2 I re-examine the dominant narrative of primary science as told by researchers (Osborne and Simon, 1996; Harlen and Holroyd, 1997; Murphy and Beggs, 2002; Beggs and Murphy, 2005), and science educators; a story which historically tells of long-term failure (The Royal Society, 2012; CBI, 2015). Previous research in primary science collectively told of primary teachers who had limited science knowledge and lacked confidence to teach this subject (Wragg, Bennett, and Carre, 1989; Bennett et al., 1992; Sharp et al., 2009). The outline of this story is told from its beginning by HMI (1978) and continual re-enforcement during the next four decades (HMI, 1989; Bennett et al., 1992; Postnotes, 2003; Ofsted, 2011; The Royal Society of Chemistry, 2014). This re-examination enabled new perspectives to be gained as well as the development of new learning about this dominant narrative.

This dominant narrative is also found in policy statements concerning primary science (HMI, 1978; HMI, 1989; Ofsted, 2011, DfE, 2013) which portrays the role of science education, including primary science, as a way of ensuring enough future scientists, a phenomenon known as 'the pipeline'. The prime role of primary science is on the product - pupils' future achievement and attitudes, which are compared with teacher behaviours or competencies. The research views teaching as a linear process, with the teachers' behaviour as the cause, and the pupil outcomes the effect; resulting in a 'pipeline' that leaks (CBI, 2015).

In Chapter 3, I examine the histories of the sciences and science education within these supposedly non-narrative forms. I suggest the problem with the educational definition of the sciences is entwined with an idealistic view of the sciences in education. I advocate that *Science* is an educational term, because '*the sciences'* were not originally one entity but were unified as a political device by Whewell in the 1830s. Whewell (1847) was possibly the first person to undertake the mission of promoting a public understanding of science. He proposed that through understanding science, the working lives of ordinary people could be improved. One of the by-products of creating the terms science and scientists was a simplification of the types and processes involved, resulting in the creation of a myth of both science (Kitcher, 1993) and how the sciences operate. In examining these issues, I have come to accept that scientific explanations are analogous to stories (Ogborn et al, 1996; Avraamidou and Osborne, 2010) demonstrating that the sciences and narrative are closely linked.

Chapter 4 discusses knowledge and one of the personal challenges of this study has been the position of the sciences, envisaged as objective 'truth' (fact) and other domains of knowing. Truth throughout this work was an examination of scientific realism, where I questioned what is in the world and what is true about it (see appendix 1). I challenged my view of knowledge, its formation and composition as a direct result of working with these successful science educators. In this study I also challenged my understanding of the fact/fiction dichotomy and have incorporated narrative explanations to demonstrate that 'narratives do live up to the epistemic standards of good science' (Currie and Sterelny, 2017, p.19). I came to understand that narratives help people to understand their natural world (Norris et al, 2005), by interrogating the abyss that exists between 'the ghost of objective culture' and human life (Bakhtin, 1993, p. xio). This reflection and learning resulted in the generation of two models to support my understanding; these are presented in chapter 4 and then used within the biographical chapters.

The ontological debate about the sciences, what and how they operate is a personal challenge. In this work I examined several positions, firstly that the changing nature of science is the result of there being no truth or world 'out there' (Rorty 1979; von Glasersfeld, 1989). I find this to be an understandable response to the world of the quantum, and the resulting of rapid changes that took place in the sciences the early 1900s (Hacking, 1983). A different explanation is that these changes are a direct result of changes to the way data is sensed because of superior equipment (Kitcher, 1993). Another stance is that the sciences are globally progressive because of environmental change (Hull, 1988) and therefore the sciences will always change. Yet, it could be the historical examination of science which led to the questioning of the cumulative objective view of the scientific knowledge, (Kuhn, 1969) which was caused by the changing understanding of the nature of scientific knowledge. It is possible, that in the same way that the scientific revolution of the seventeenth century altered how and what the sciences appeared to be, the quantum changes might be only the latest transformation. The ideological issues associated with quantum age consequential resulted in challenges to both scientific knowledge and belief – elements of these issues inform the literature review that comprises Chapters 2, 3 and 4.

In chapter 5 I will discuss the auto/biographical approach which attempts to understand phenomena through the meanings that the science educators assign to them. Within the narratives, the stories of all participants have connections, and how the world is assumed to be and understood interrelate. The auto/biographical approach acknowledges that the values of all involved influence all aspects of the research process, in the same way that scientists' observations influence the outcomes of the experiments (Heisenberg, 1924; Cassidy, 2001), or using the narrative of the quantum world, where two quantum entities that have interacted remain entangled regardless of the distance between them (Bell, 1964). Narratives are noteworthy because they fill the world with agents and plots (Bruner, 1986) and the overlap between narrative and non-narrative (Nielson, 2010) provides meaning to life at both a personal and a cultural level, providing both community and cultural cohesion (Polkinghorne, 1988).

I followed C. Wrights Mills' (1970, p.216) suggestion to use 'life experience in intellectual work as a way to understand the interconnectedness of how society works' which for someone fixated on certainties was a challenge. That this type of study can come in many forms, lengths, focuses and perspectives and that I, as the writer, will play a part (Smith, 2012, p.12) was also a learning experience. These issues and how the material, was collected and interpreted are discussed in detail in Chapter 5. As the issue of terminology is contentious, I will use the terms auto/biographical to describe the interactions between myself and others, but I will also use the terms narratives and stories, for they all bear important family resemblances (Bruner, 2004). I am aware that this hybridisation alongside my inability to use language as skilfully as most who use this form of research, are an ongoing issue. Yet without this approach I doubt I would have learnt as much.

Chapters 6, 7, 8 and 9 are the individual biographies, detailing each participants' science life story and their understanding of the nature of science. These narratives specify what is distinctive about each participant and no single life story shared within this work is a model for them all. I did not edit out elements unrelated to the main research question because the participants helped to select the themes that were important. These successful science educators influence primary science and their stories are like a kaleidoscope (Stanley 1993), where all the pieces of the story of primary science are present but are changed depending on their understanding (Lunn, 2002; Beggs and Murphy, 2005).

The stories that these successful science educators tell become the plot that link otherwise random events and give meaning to their professional lives. The narratives of the sciences and of the research participants, create a worldview that is different from the world of everyday observations, where children as 'little scientists' whose teachers lack scientific knowledge is the dominant narrative. Within narratives the significance of all events is viewed from the perspective of the outcomes, as 'narrative explanations are retrospective' (Polkinghorne, 1988, p.21), which makes this cause and effect different from deterministic science. Yet narratives are also a structure for organising knowledge (Hendry, 2010; Nielsen, 2010; Bruner, 2006) and in the sciences 'narratives create a productive order amongst materials with the purpose to answer why and how questions' (Morgan and Hirschman, 2017, p. 1).

Narrative research is a useful mechanism to explore beliefs, values and social understanding and working with these participants has changed my understanding and, in one case, theirs. The entanglement has had an effect, and the effect will be discussed in Chapter 10. The auto/biographical nature of the work has resulted in a fluidity so whilst Chapter 1 narrates my *living theory* of science, my influence is found throughout the work and the final chapter demonstrates my learning as a result of engaging with the narratives of others.

0.4.1 The participants

Examining the world of primary science from the perspective of successful science educators was a privilege. All participants are anonymous, and the material used has their agreement (details are provided in chapter 5). These participants have differing roles and forms of experience. More detail about each is provided later (Chapters, 6, 7, 8 and 9), but here the intention is to provide a brief introduction; all names throughout are pseudonyms.

Ben (Chapter 6) started his career as a secondary science teacher who then transferred to the primary phase. In the interviews Ben focused on teachers having science subject knowledge and the idea of some learners who have a fairly 'sciency' brain. Ben's view of science involves children undertaking wow 'activities which will set them on that path to become scientists. Controversially, Ben suggests long term science is only for more able children. Ben changed roles during the time I have taken to complete this study and is now working with teachers across the whole of the United Kingdom in a senior science role.

Stephanie (Chapter 7) has been involved in science education as a science adviser for more than 30 years, influencing teachers both in the United Kingdom and abroad, and she has had an impact on many aspects of science education. Stephanie describes how she 'fell in love with the thing 'Because of what I was suddenly learning about science that I did not know before.' Stephanie thinks science is for all children and is successful when the child and the teacher learn together. Stephanie is defined by her role in science and science for all is an important element of her story.

Justine (Chapter 8) advises government on their approaches to primary science teaching, although, as she states, 'not always successfully, as they do not always listen and sometimes, they make up policy in the time it takes to ride ten floors in a lift.' Justine views all children as 'little scientists' and vividly paints pictures of children exploring on beaches and developing their everyday knowledge of science. She is adamant that science is about whatever they want to learn. Her motto is 'make it matter', and she hates what she terms 'Frog Marched Discovery'.

Peter (Chapter 9) has been involved in science education for more than forty years and has been influential in the creation of National Curriculum documents and teacher development materials. Peter's approach to education is that it should be 'an authentic activity' so that pupils are not misled, it is 'about getting them involved and responsible rather than just recipients'. Peter was initially trained as a scientist.

Others and I reflecting and thinking on what they do, and why, has been an important part of this research and has provided an opportunity to gain other insights into science teaching in primary schools than those I previously held. The stories about ourselves are not made up from first principles each time, and they change with new circumstances and relationships and, 'we constantly create ourselves' (Bruner, 2004, p. 4), and our stories are both construction and reconstruction using memories from the past and future hopes and fears. Therefore, these stories allude to society in general and the beliefs that are held; the things that everyone knows.

0.5 Buckets to collect rain

My thinking has developed in the course of this research and has had an influence on the structure of the thesis. I initially set out to hunt for an answer, because my understanding of science was informed by my own education and I 'accepted the inductive myth that theories somehow emerge out of a proper collection of facts' (Curtis, 1994, p.421). I considered that there were scientific ways to research that differed from other types of research. However, as this study has transformed my viewpoint, I no longer expect to capture 'the truth', nor consider there will be only one truth. Just as 'buckets put out in the rain' (Roberts quoted by Cuban, 1993, p.248) cannot, nor do not, catch all the water. This study hopes to catch some 'rain' that might be used to further inform the debate and perhaps, in the future, help to improve primary science education.

A key feature of catching 'rain' depends on an appropriate method. Sometimes unsophisticated methods are the most effective. Standing holding sugar paper in the rain allows children to answer the question 'Are all rain drops the same size?' This simple everyday activity develops understanding and awareness that with science it is possible to find answers for many questions. How questions are answered and 'what is knowledge?' are fundamental to this study. The method selected does not view science and narrative as two distinct research genres and I do not hold a view that narrative research is post-science, or that only science knowledge is valid (Hendry, 2010). In this search for an understanding of the term truth, I discovered that truth is not simple and there are many kinds of truth as identified by Feyerabend:

> Do you really believe there is a brief explanation that would satisfy you and contain all the ways in which something is true? Or more generally that there is something which can explain why people say the Big Bang is true, the existence of God is true, the suffering of Christ is true, the wickedness of my mother-in-law is true, and it is true that I am hungry right now? (Feyerabend, 1996, p.14)

Truth is indeed many things and this thesis examines many aspects of primary science.

0.6 Stories of science

I began this work studying an issue which never appeared to improve and read in detail the original research upon which the primary science education story was based, finding it flawed in several ways. However, by working with the auto/biographical material, and struggling with some difficult questions regarding what is in the world, an overarching element emerged and centres on the whether the dominant narrative in primary science is accurate. The title 'stories of science' emerged because whilst analysis of the life stories of educators was the methodology, as time went on, I realised that the sciences were also a storied subject rather than an objective and impersonal one.

Humans have always told stories to explain things that puzzle them – for example, 'how the world began', 'the meaning of the stars in the heavens' or 'trying to make sense of natural disasters.' All stories of science involve persuading others about the way things 'are' (Feyerabend, 1981). Whilst the stories of the sciences today are complex and involve, for example, quarks, Higgs boson, dark matter and gene manipulation, they are still assembled by the same processes as science stories of the past. Life stories involve close and detailed study, about looking at particular instances in the same way that doctors can learn from case reports (Hurwitz, 2017). Maybe teachers and teacher educators may be able to learn from these stories of education.

Two of the functions of stories are to entertain and educate (Bruner, 1986), and the process of listening to the stories of science has been a deeply thought-provoking experience and one which has challenged my beliefs and understanding. I set out with a hope that the stories of science educators might mobilize action and influence the debates about primary science and science education. This is a story that attempts 'to catch some rain', and it identifies that in primary science education not all drops of rain are the same size.

Chapter 1: My story of science

I began this work hesitant about using a research approach that focused on life stories and not on 'hard data', thinking at that time that they were different entities. As a result, I used biographical materials in order to avoid writing myself into the work. (Generally, the researcher's voice is not found in scientific research.) My ontology, my theory of being, was to take an external view, observing and describing what others do rather than using an internal, participative approach (Whitehead and McNiff, 2006). What I learnt by working with the biographies in a participative way, was how little I really knew about primary science and science in general (Appendix 1 details this process). Undertaking this research taught me a great deal about myself and my approach to science education. Consequently, I began to unpick my own educational development. I pondered on many approaches all of which related to the question posed by Whitehead, 'How do I improve my practice?' (Whitehead, 1989, p. 51.).

1.1 Introduction

I had spent many years with a view of science that worked professionally and personally, but without interrogating the Legend of science (Kitcher, 1993). Unintentionally, it also caused me to judge all other forms of knowledge that did not conform to the concepts and universal laws of my chosen scientific world as somehow less valuable. My views of science and the sciences have altered as a result of working with successful science educators and my frames of reference have changed. The making of a worldview requires 'weeding out and filling in' (Goodman, 1978, p.14) allowing people to find they were expecting to find or blinding them to things that hinder their actions. I have learnt that the process of filtering experiences (Reed, 1992) and ignoring aspects that do not fit into one's own worldview, contribute considerably to how understanding is constructed (see section 4.2.2).

I was forced to explore my own practice as a result of working with successful science educators, who produced their explanations of what constituted good primary science. It is clear to me that Whitehead and McNiff (2006, p. 13) are correct when they state that 'Each person already has their own tacit theory within themselves about how they should live, that work collaboratively to make sense of what they are doing.' What I found was that these science educators all held very different tacit theories, and apart from Ben who reflected upon his practice as part of the process, their views did not alter.

1.1.1 Structure of the work

I debated endlessly whether to include a chapter which told my story of science and the inclusion of this chapter, focusing upon my own understanding of science and my science life story, was included late in the process. Initially I thought that the auto/biographical reflections would be more authentic if they emerged as responses, rather like those of a swinging pendulum, moving between the points of view held by me and those held by the participants (Cooley, 1922) scattered throughout. However, I found that this approach interrupted the stories of the successful science educators, making the whole thesis disjointed. Examining the process through 'Living Theory' (Whitehead, 1989) provided a new perspective to this work.

Although there is only one narrative of my life, this chapter is divided into distinct sections. Like many people, as my life has unfolded, my beliefs have changed. While the chronologically-centred account explains the significance of events that occurred (Polkinghorne, 1988), my current beliefs differ greatly from those of my earlier education. The changes in my beliefs are as a result of my changing ontological and epistemological understanding at different times. Naturally my current understanding plays a central role in shaping my work. I find the analogy of a river helpful, if it is understood not merely as being a route from source to sea, but instead the whole journey. Inevitably life stories change according to new circumstances, relationships and understanding (Bruner, 2004) or, as Mink suggests, '…To think of it in both directions at once, and then time is no longer the river which bears us along but the river in aerial view, upstream and downstream in a single survey' (Mink, 1970, p.555).

The chapter starts by setting this work within the framework of my current understanding. Although the work of Whitehead (1989) has value, this work remains auto/biographical rather than taking a purely action research method. I have reframed this work**,** beginning with my current epistemological position**,** in order to make the whole thesis easier to access. As a result, I will require the reader to think of the river in both directions at once and to see all in a single survey. There are**,** however**,** disadvantages of starting at the end and although easier to read if you understand my position, it is less challenging because you will not have to question your position or my own throughout each section.

Throughout the work I use the work of Bourdieu (1990) and will define some of the terms in this introduction:

- *Habitus* is the socialised embodied disposition that shape whether science is accepted as a worldview (providing players with a feel for the game.)

- *Capital* includes the social, political economic and symbolic resources that are given or gained (this is the hand you are dealt.)
- *The field* is the socio-spatial space, (which is how you know the rules of the game and how the game works.)

The fit between the habitus, capital and field**,** shapes future outcomes and this chapter discusses this fit.

1.1.2 My current position

My view of science**,** and science education**,** changed when I selected an auto/biographical research focus for this thesis. As my ontological position changed my epistemological approach also altered, as I questioned all aspects of the science, I thought I knew. The journal entry below, provides some context:

> In 2015, I found myself walking on a coastal path in Cornwall when I came across shells in a field. They were some distance from the sea and as I collected them for a science teaching activity later that week, I wondered how they had arrived there. I began to think of ideas or stories about why they were there; were they collected by children and had then dropped from their buckets as they ran back to their holiday home? Could it be that they had been thrown up the cliffs and deposited in the field by waves on a very windy or stormy day? My view of science stated that observations were the starting point for science, but I had read that science also needs a theory, or an incentive for a scientist to create a theory; otherwise scientists would browse like cows in a field (Medawar, 1969)**.** The next day on another cliff walk and in a different field**,** and again about 150 metres from the sea**,** I found more shells. This time some had damage, suggesting another story; could these have been dropped by gulls? I continued to raise questions and create stories about how the shells had arrived in each location and to review my previously held ideas. I realise now that induction does not operate well in a world without regularity, or where objects cannot be seen at all, and that all observations are influenced by the data that was perceived and filtered by my own perceptions. As everything that is known about the world, is a result of individual acts of perception so the constructs cannot be value-free but are a product of what has been (Bourdieu, 1990).
>
> Personal Journal entry (June 2015)

The reflection on events, such as collecting shells for teaching activities, were part of a process that changed my naive views. This autobiography chapter could have additional materials about my study but as this work is continuing, it remains incomplete. Whitehead and McNiff (2006, p.30) identified that theories constantly need revising and reforming… 'theories are always in a state of live modification.' So, I expect there will continually be changes. Furthermore, whilst my view of science and science education have changed, I am still committed to science education.

The greatest changes have taken place in my presupposition and motivations, which have moved from a naïve positivist approach to a critical realist position:

> The initial shell observations made me realise that making observations is a selective process, and this approach might fit more into a relativist position (Carey, 2004), but instead I accept that there are shells, children with buckets, and very large seagulls that exist regardless of what I am doing, whether I am there to see them or not. A critical realist approach is now my epistemic model. Even though I questioned all I knew about the sciences, I began to identify that the approach I used in teaching was very simplistic and not representative of the sciences.
>
> (Personal Journal entry August 2015)

The critical realist position accepts there are many methods of science and that science education and the sciences are not the same thing. I challenge my previous views that were influenced by public policy. Now I am now more likely to associate with the wider society view of science rather than subscribing merely to government or professional bodies' perspectives, or research funded by these groups. Those who now support and influence my development are very different and originate from research methodologies I was previously unaware of. My understanding of science has changed more than once. This chapter tells my science life story and it was challenging to write, because bringing self into academic writing still feels uncomfortable.

1.1.3 Epistemological position

My education was the source of the river that influenced my initial beliefs about science, and the next part of this chapter covers this time. The last section narrates my time as a primary school teacher and subsequently a science Advisory Teacher, a time of a widening river. Both these stages were growth phases and resulted in my current role as a science educator.

The theories that influenced my initial position were accepted unquestioningly as 'the correct way of thinking' (Whitehead and McNiff, 2006, p. 30), although I was unaware that there were other ways of viewing the world or that theories have political interests (ibid). My position was one of acceptance of propositional theories where there are correct (scientific) and incorrect (non-scientific) positions.

My current epistemological position is that narrative is how the world is understood (see Chapter 2). I suggest that no worlds are possible without words, symbols, and action, for without them there are no stories; and that the processes that occur in the sciences are also a fundamental requirement of all stories. Previously I held the perception of science as being constructed by an accumulation of separate facts, one fact after another, each independently certified by experiment. Yet this is a false picture because science is as much the work of imagination as the result of experimentation (Harre, 1972). I now accept that the sciences have complex stories to communicate; stories that have changed over time. For instance, initially the world was perceived to be composed of primary universal matter, earth, water, fire and air, where things were thought to happen because of necessity or change, where stones fell because they needed to get back to their place on the Earth. Today I accept that theories in science are novels, where the facts are non-fiction, but the theory is the work of imagination. Science continues by "a leapfrog process" of fact accumulation, where a change in theory can turn a previously known fact into a falsehood (Harre, 1972).

Bruner (2002) assisted my acceptance that the paradigmatic and the narrative were in league and that, whilst there were differences between them, together they provided interesting new understanding about human existence (Bruner, 2002; Nielsen, 2010). Narratives concern the past and science education is all about past events, often using facts that scientists today no longer accept as valid.

I will now take a chronological approach but like Mink's river, this is a story that should be viewed in its entirety because any reflection on past events is undertaken with information that was not present at that time. This story continues with my biography and my earliest memories of science.

1.2. Biography: My earliest memories of science

If this story was a fairy tale, it would start with me knowing that I would have a science-based role, but the reality is very different. I had no idea as a child what I wanted to do or become. It appears that there is a difference between personal motivation, enjoying science, and thinking that science is the future career option. These are different constructs - one concerns personal enjoyment, and the other a future role in science (Kjærnsli and Lie, 2011). My only memory of science in my primary school was the nature table and spending one afternoon a month measuring and observing aspects of the environment, and recording what I saw in a journal, which was an enjoyable experience. My love of the science journal was not only because of the nature element but because I was not sat at a desk having to write things down. The journal was more like an art book than a notebook and felt special, mainly because no-one marked it.

I always struggled with writing and spelling. At the age of nine, I was formally diagnosed with a form of dyslexia; until that point, I had been treated as a 'less-able' child. The diagnosis of dyslexia did not change the ability label because it did not affect my literacy skills, but it provided an explanation that I could understand. However, it was not until I was given a typewriter, at the age of

11, that anyone could make sense of anything I wrote. These early educational experiences were instrumental to my later love of science, especially physics.

1.2.1 Influences that led to science subjects

My father was an engineer and my uncle a chemist who worked for Pfizer, a large multinational chemical company, so my science capital (Archer *et al.*, 2013) could be designated as high. Archer *et al.* (2013) suggest that children's aspirations are largely formed within the critical time frame between the ages of 10 and 14, and that one of the greatest factors on the take-up of science subjects is family 'capital', with parental support having the greatest influence on learners' science aspirations. Science capital is based on Bourdieu's idea of habitus, field and capital (1990). Bourdieu's theory links the objective and subjective, the social world and the world of personal experience, and is an approach to frame my experiences. I did have a chemistry set, and at the age of seven made candles in the kitchen. Although science capital research (Dewitt et al., 2011; Archer *et al.*, 2013; Dewitt *et al.*, 2013) suggests parents and home to be highly influential, this was disputed by PISA data (OECD, 2006) where 'the predicting power of the factors, home, parents' job, and performance turns out to be surprisingly small' (Kjærnsli and Lie, 2011, p.131).

Whilst studies show that students' interests are decisive for the educational direction they choose, most studies do not demonstrate in which ways they are decisive (Troelsen, 2006, cited by Kjærnsli and Lie, 2011, p.124). Incidentally, my family background has not resulted in my siblings undertaking any science-related activity. In addition, neither of my children followed science-based subjects or careers, even though they spent their early childhood visiting science museums, and both their father and I have science-related careers. I would therefore suggest that my personal interest in the science subjects played the most important element in my selection of subjects. Science, and particularly physics, alongside Physical Education (P.E.), were the subjects in which I excelled. I had an aptitude for science, and I do like puzzle solving (Kuhn, 1962). I think it is highly likely that this aptitude was also linked to the lack of writing in both science and P.E. (Beggs and Murphy, 2005), but this judgement is made with the benefit of hindsight. At the time I just knew science was something I could do.

My clearest memory of science at secondary school was the physics lessons. I remember vividly the physics teacher's method: she did not take the approach of proving a known fact, the approach used in both the chemistry and biology lessons, where the title was the facts that was to be learnt that day, for example, 'to prove that oxygen is needed for combustion'. This approach is common in science lessons where 'investigative work comprised of testing an already well-established scientific idea' (Taber, 2014, p.126). In physics, the teacher introduced a problem and the solutions were only linked to a scientific theory at the end of the lesson. Though I did not realise it at the time I was accepting a scientific way to view the world. I went on to study biology, chemistry and geography at A Level because the school I attended did not have an A Level physics teacher. The fact that I continued to study biology and chemistry perhaps suggests that I, like the adolescents of today, was not significantly affected by the instruction style or activities in the science lessons (Kjærnsli and Lie, 2011). This finding challenges the perceived view that the type of lesson and the role of the teacher are paramount (The Royal Society, 2012; Royal Society of Chemistry, 2014; CBI, 2015) in making the lessons effective.

The science teachers varied and although some lessons were more enjoyable than others (physics rather than biology), I learnt early on that in order to succeed I needed to memorise things. This coping strategy was effective within my early education and particularly in science-based subjects. I needed to achieve, not because my family had expectations, but because of a personal feeling of mastering and understanding that was motivational (Kjærnsli and Lie, 2011). I was good at science subjects and learnt the 'rules of the game' (Bourdieu, 1990), but I can also relate strongly to Eccles' (1993) model of achievement-related choices which identifies that there are two sets of beliefs that influence decisions: the individual's expectations for success, and the importance or value the individual attaches to the various options that they perceive to be available to them. The model predicts that people will be most likely to engage in subjects that they think they can master, and those individuals' expectations for success depend on their self-assurance in their intellectual abilities compared to their estimation of the difficulty of the challenges they will meet.
P.E. and physics were the only subjects where I received A grades on school reports and, whilst I loved playing sport, being good at physics provided more kudos. So, physics formed part of the social space I occupied, which then gave rise to later actions, for example taking a science-based degree (Bourdieu, 1990). My developing habitus, which Bourdieu defined as 'a system of durable transposable dispositions' (Bourdieu, 1990, p. 53) resulted from an acceptance of the field of science, including the ways of working and the organisation of facts.

The research into the value of undertaking some subjects rather than others (Eccles and Wigfield, 1995) has utility both in my own and participants' stories. This model can be conceptualised in terms of four features: three values that can be thought of as positive (attainment, intrinsic value, and utility) and one which is negative and is termed *cost*. Cost is what is lost, or suffered, as a result of undertaking the activity (Eccles and Wigfield, 1995). It seems that the interconnected core values of 'feelings, thinking and being' (Maton, 2014, p.51) were related to science subjects and my habitus.

My developing habitus resulted in my selection of science subjects post-sixteen and provided for what (Eccles and Wigfield, 1995) call 'attainment value'. It represents the importance of doing well in terms of a personal scheme or core values and being good at science subjects added to my personal core values. The perceived difficulty of the science subjects, both by other pupils and by teachers in my school, provided kudos, as I was perceived to be able to understand something that others could not. This predisposition to science and the relationship between this and the circumstances of my life at that time were linked. I had worked out where I would do best, given my disposition and the resources available to me (Maton, 2014). This was more important to a child who had been considered a failure for much of their previous educational life, but this is a narrative of hindsight. However, I think the intrinsic value of the science subjects I studied was also important, alongside the joy of studying science.

Looking back at my earliest memories of science the overwhelming emotion is the joy I found in science lessons. I loved chemistry 'practicals' where I was given a sample of a substance and told to identify what it was and how I knew. I am sure the opportunity to burn things also contributed. In contrast were English and French lessons where there were field-habitus clashes (Bourdieu, 2004). When habitus and field are linked, the end product is feeling 'like a fish in water' (Bourdieu and Wacquant, 1992, p. 127) but when the requirements of the field, for example the language-based nature of English and French are very different, then there can be field/habitus clashes. I was not considered to be a potential scientist or a bright kid (Costa, 1995) by my teachers. I loved identifying plants but was unable to undertake animal dissection as I was too squeamish; and I still remember leaving a lesson where the smell of formaldehyde and death remains a strong impression. This intrinsic value of the science subjects relates to the personal enjoyment of many of the activities but not all. Yet as a habitus is as unique as each person, these experiences built my understanding of the field of science which was reinforced by my ever-evolving science dispositions (Bourdieu, 1990). I valued the problem-solving nature of science learning, the way things could be worked out from first principles, and that success required only a logical thinking approach and not the production of large quantities of text. However, biology required memorisation, something in which I excelled early in my educational life, to compensate for my spelling and writing failures. Whilst there were few personal 'costs' (Eccles and Wigfield, 1995) to studying science, there were many more opportunities. Yet I cannot suggest that science subjects had a clear, long-term utility value for me at this time; I studied them because I was good at them.

1.2.2 Utility value, intrinsic and extrinsic comparisons

Utility value in the model (Eccles and Wigfield, 1995) is defined as how studying a subject will meet short- or long-term goals. My short-term goal was simple - carry on doing subjects I enjoyed - but the long-term goal was less distinct as I did not know what I would do. Research suggests that the concept of self is informed not only by how well students do compared to others (extrinsic comparison), but also how performance in one subject is compared to performance in other subjects, the intrinsic comparison (Marsh and Shavelson, 1985, p.120). The extrinsic reward element was not evidenced strongly in my story until I received my O level results.   Instead, more pertinent were the intrinsic features, related to domain-specific beliefs and subjects in which I had been successful in the past (Marsh and Shavelson, 1985).

The success in my O Levels in all science subjects (intrinsic comparison) was a surprise to my teachers, parents and myself. Overall, I achieved well in a significant number of subjects when compared to other students at my school and my siblings (extrinsic comparison) (*Ibid*).   As a result, I began to expect to have success in the future and this success supported a positive personal image (Eccles and Wigfield, 1995). I continued to do well with the subjects at A Level but still had no clear idea of what next (apart from the certainty that I would never go to secretarial college). When I achieved an A grade in geography at AO Level at the end of lower sixth, having never studied this subject at O level, it was suggested that I should apply for university.

1.2.3 Working with others: Science at University

Success in exams led to reading for a science degree at the University of Liverpool and it was here where I really developed a deeper understanding of science and, in the analogy of a river, my life widened out. I had selected a hall at university with units comprising of two bedrooms and one bathroom, which I shared with Fiona, who studied Egyptology. My course required daily attendance at lectures with four additional afternoons (1-5pm) undertaking laboratory work. Egyptology, by contrast, had only eight hours contact a week, and appeared to involve mainly personal learning. Science practical work, whether in a lab or as fieldwork, was central to my degree, and was generally supervised by post-doctoral students.   My experience of learning about an aspect of the sciences was integral to being part of a social institution - many like-minded students taking part in 'science'. Scientific practices were concerned with solving problems and finding patterns and trends in results.

This science was undertaken within the confines of what is known to be 'science' (Ziman, 2000). I was learning that 'scientific credibility required a suitable scientific style of detachment' and this time is where I cemented my understanding that science required 'writing in the third person passive voice to make nature seem to speak for itself' (Morgan and Wise, 2017, p.3). I learnt about getting results, following practical schedules and working with others; I was never alone in the lab and group worked helped to develop an understanding of how to be even better at science; this was a time of persuasion (Kuhn, 1962) and further enculturation into a science world view.

My personal style and biography suited the study of the sciences, and involved courses in Botany, Chemistry, Biochemistry and Physical Geography. I spent my time working with things that could be seen and measured. When experiments did not proceed as expected, it was often clear that operator error was to blame, and the tests were repeated. I was practising the trade skills, developing scientific facts and working with more well-informed others who had previously trod this path, my habitus developed further. I wondered if I might have enjoyed something as exotic as Egyptology, but I felt safe studying the subjects I knew and felt in tune with. The effect of industry and professional bodies influenced the equipment and the theory, but this was not part of my understanding at the time. When I completed my degree, still unsure of what I wanted to do next, I applied for a range of opportunities, including banking and the civil service, as well as making an application for a Post Graduate Certificate (PGCE) in Primary Education. I enjoyed studying science subjects but even after university had no clear idea of what I would do next. I undertook a teaching qualification (PGCE) to keep my options open.

1.3 The teaching years

This section includes the time from starting a PGCE until I began this PhD. All these experiences are linked by a developing, and then cemented, understanding of the way things were done in science, or 'doxa' (Bourdieu, 1999). These years form a central part of my understanding of primary science. The story moves on from the first teaching posts, into Advisory Teacher work, and then through the changes that beset primary science education as part of the National Strategies era (DfES, 1998), into a role working at a university. In Bruner's (2004) language, the introduction of the National Strategies was a time of trouble, which could also be identified as a hysteresis (Bourdieu, 1984), both personally and nationally for primary science. Running alongside this work story were changes to my home life which gave me the opportunity to move from the North West of England to the South East. Some themes like constructivism span all time frames although they are understood in different ways. The story begins with the training for a PGCE in Primary Education.

1.3.1 Personal Style: Training as a primary teacher

The PGCE was supposed to be a stop gap. When I applied for the course, I had no interest in teaching, but I was waiting for second and third interviews for other jobs that I thought more suitable. Taking the teaching course provided an excuse to continue an independent life at university for another year, and I was encouraged by friends who did want to be teachers, and a grant. The lectures in the first term of the PGCE were not demanding and the science content of the course revolved around one single two-hour lecture where we observed candles. At this point the science I knew, and science education were unrelated.

The turning point for teaching happened when I was on first placement in a primary school in an area of Manchester. The class teacher who should have been supporting my experience was absent, and the headteacher popped his head around the door of the classroom on my second day and told me that I was doing great; he disappeared and did not visit again! I enjoyed the teaching, perhaps as there was no-one there to tell me I was doing it wrong. I developed, over the next month, ways of working that appeared effective, although I was grateful when the class teacher returned - not because she took over, but because there were then two adults within the classroom of 25 five-year-olds.

I completed the placement, where, in hindsight, the children taught themselves through the highly structured and directed maths scheme. My role, as I perceived it, was to select a topic of interest, to read stories, and make sure all children completed the four or five tasks that I set each day. There is a part of me, whilst reflecting upon this, that is uncertain that it was such a good method. However, at this time I was unaware that the curriculum could be understood 'in terms of questions of power, politics, and ideology, both within and beyond schools' (Young, 2008a, p.1). I felt at home in the classroom, I enjoyed the children's company, and whenever my tutor appeared, my teaching was judged to be good. I had found what I was supposed to do and be, and as a result I never went to the final interviews for other jobs. I did not teach science at this first placement school and the only science lessons I remember teaching, before I had my own classroom, was growing cress as part of a history topic on Egypt and the Nile. This was during the second half of my course and where it crossed my mind that Egyptology might have been a more useful degree.

My first teaching post was in an urban infant school situated in an area of severe socio-economic deprivation within the North West of England, where I had charge of a class of 5-year-olds. I felt I had the opportunity to effect change and take control over the classroom and all those within it. I selected the topics that were studied, which included the Romans, the Vikings and the Lancashire mills, depending on what I felt the children would enjoy and my personal interest. As I did not have any other experiences to draw on, when I first started to teach primary science my influences came from my own secondary education (Lortie, 1975). I conceptualised teaching based on past personal schooling experiences (Saban, 2003).

My teaching was set within the context of a very different time, different from a classical bureaucratic interpretation of education in which the 'legitimisation of educational change and development firmly rests with politicians and administrators' (Gruber 1987, p 58.). Gruber's view of the English system reflects my memory of this time and that of some of the other participants in this research. These post - 'Plowden years' (1967) resulted in the education system in England being very different to that of today and distinct from school systems in other parts of the world, such as in Germany and Austria (Gruber, 1987). I recognised aspects of the research suggesting that 'the teachers had freedom to innovate and there was variation, not seen in German schools, where all schools are the same' (Gruber, 1987, p 60). I was not innovating, but instead following what the headteacher required and I selected topics that made learning enjoyable. Gruber's research was set before the National Curriculum (DES/WO, 1989) and before the beginning of classrooms' doors opening. My classroom was a rectangle, I was the person in control, and the door was invariably shut!

The introduction of the National Curriculum (DES/WO, 1989) provided challenges, but was unlike the change in education that was to come (DfES, 1998). Whilst the curriculum content was prescribed, the methods and approaches were not. For many teachers, science was not something they had previously taught, so rather than changing practice they were starting to teach something new. Each year my class changed, as new children became 'the class' and their home lives, interests and even gender composition influenced the classroom routines, as every classroom of children and each lesson epitomise unique contexts. Yet I accepted at the time that there was one version of science. I did not contemplate that it was possible that 'there are different ways to understand science' (Smith and Neale, 1989, cited by Kagan, 1992, p.74). Although my subsequent role as an Advisory Teacher was to promote a view of expert teaching behaviour; I was still a spectator (Bourdieu, 1990). The National Curriculum brought legally binding changes, which I saw as opportunities rather than challenges. One of the opportunities was the offer of science CPD, something which, prior to the introduction of the National Curriculum, had been limited. This training was to have a major impact on my teaching, although not on my beliefs, mirroring research that suggests that enforced change can amend practice but leave beliefs in place (Hargreaves, 1994). These changes will now be expanded upon alongside the understanding of my stable belief systems.

1.3.2 The influence of others: The opportunity for training

I attended training by Local Authority advisers and Advisory Teachers (ATs), who delivered propositions put forward by the Assessment Performance Unit (APU) which were related to the ideas and skills children held (Russell and Black, 1988). These ATs influenced my teaching by demonstrating what could be achieved using simple materials and resources, which could have been considered as everyday 'rubbish' (Qualter, 1999). Their utilisation revealed that primary science was not about specialist equipment but about what primary children needed in order to learn effectively, alongside a belief in the skill of the person in charge of learning. This was my introduction to primary science, which was very different from my own science education.

Research on the role of the science Advisory Teachers (Kinder and Harland 1992; Qualter, 1999; Harland and Kinder, 2014) would support my experience that the most important feature of CPD was to develop an understanding of effective practice that corresponded to that modelled by the person running the course, something termed value-convergence. In a study focusing on how teachers became good at primary science, Qualter (1999) found that 'good teachers' identified that teaching science in primary school required them to abandon the science from their own education in secondary school. As one teacher put it:

> 'I had always thought it was, you know, … turn to page 42 and we will look at this flower, and then this is the petal and this is the stamen and the everyday world isn't there. And I don't want to teach like that. So when this new approach to science came in that's when I became interested in science'. (Qualter, 1999, p.82)

This 'turn to page 42' approach was symptomatic of secondary science and I valued the new primary approach. The focus on the everyday world, where finding 'tummy buttons' on beans, or placing objects in matchboxes so the children could guess what was inside, were part of these new experiences. These types of activities suited the children's interests, and my belief about empirical, positivistic science was cemented by such approaches. I adopted this more child-centred, less didactic approach alongside approved activities with my class. I would have been classified as an enthusiastic teacher (Jarvis and Pell, 2004), even though I would now challenge some of their results and conclusions (see section 2.3.4). However, I will accept their nomenclature of a 'fired-up' teacher (ibid), as I took full advantage of any science training on offer.

Prior to attending these CPD courses, I thought all children should experience science, although I taught a watered-down secondary science, because that was all I knew. I taught the children the science facts and experiences I thought important, that emulated my own view of science as I was not aware of any of the epistemological concerns that I have more recently encountered, such as reinforcing beliefs and myths 'that are inherent in scientific ideology' (Nadeau and Desautels, 1984, p.8).

Returning to the analogy of the river (Mink, 1970), the river was widening out and new tributaries were joining, with few eddies or currents. I would classify this stage in my career as a time of naïve realism, where I accepted that the world was as I perceived it to be. My stance supported the view that 'we all believe the Earth existed before there was man to create it with his imagination' (Metcalf, 1942, p.58). Naive realism is the ideology of common sense and by directing my pupils' attention to their everyday world I continued their daily awareness of 'real life'. There was no aspect of the science training I encountered which questioned this ideology and I learnt that this is the stance taken by most primary teachers (Nadeau and Desautels, 1984; Solomon, 1994). I held a view of a world composed of material objects that could be experienced. Most activities that I undertook with the children involved them using their sense-experience, which provided them with true information about the objects they were examining. By using their senses, the children and I were seeing the world directly as it was, and the results identified that claims made about the world were justified. In simple activities such as vibrating rulers to learn about sounds and vibrations, the learners were focused on causality. The role of science, as I perceived it, was to find scientific laws and then employ them in explanations of the effects that the children saw. This approach was not to change for more than 20 years.

I directed the learning of all in the classroom and I had no awareness that children held non-scientific ideas, so most of the work was teacher-directed and closed. Hargreaves (1994) termed this behaviour as 'safe simulations', where new instructional approaches shown on courses were used as long as they did not unsettle the accepted cultural norms. Appleton (2003) would call these 'activities that worked'. I cherry-picked selected approaches - something called 'bricolage' and 'tinkering' (Huberman, 1993, 1995) - where I thought I was adopting new methods but was really reverting to known practice. Yet, since I was a new teacher, this 'bricolage' was noticed by colleagues and was identified as an example of good science teaching. As a result, I was asked to take part in the Scientific Processes and Concept Exploration project (SPACE) (Harlen, 2007), which involved a collaborative partnership between King's College London and the University of Liverpool.

1.3.3. The SPACE years

I was introduced to the SPACE researchers and understood the project advocated a teaching approach to elicit the children's ideas about science concepts, so that together the teacher and children could find ways of testing which ideas worked scientifically. My understanding was that the teacher then corrected the ‘wrong’ ideas with scientifically acceptable ones. I was unaware that this project was following in the footsteps of the Learning in Science Project (Freyberg and Osborne 1982; Osborne and Freyberg 1985), which identified that learners held alternative concepts (Bell, 2005). Keogh and Naylor (1996) suggested that it was very common for teachers to be exposed to constructivist ideas and principles, and for these teachers to try to adopt some of these practices. The newly formed field of primary science was influenced by research projects such as Children’s Learning in Science (CLIS, Bell and Driver, 1985; Driver and Oldham, 1986; Needham, 1987) and the ATs who worked across the country. Whilst the researchers understood the *strong version* of constructivism, teachers had a weaker understanding (Bentley and Watts, 1991) acknowledging that ‘[c]onceptual change is commonly portrayed as taking place from personal intuitive knowledge to correct (scientific) knowledge’ (Watts and Bentley, 1987, p.124). I assumed that the children would accept the scientific answer presented to them and relinquish their non-scientific ideas. I enjoyed discovering the children’s ideas and would agree that while this was of benefit to the teacher, it had little relevance for the learners (Keogh and Naylor, 1996). It is only now, reflecting on my previous practice, that I understand that Bourdieu was correct when he wrote that ‘[t]o understand is first to understand the field within which, and against which, one has been formed’ (Bourdieu, 2004, p.4). Primary science, as my developing habitus, was comprised of ways of acting, being, thinking, and feeling, and how choices were made to act in particular ways and not others. These approaches look rather different from a position of hindsight. Overall, I would suggest that teaching primary science involved attempting to resolve contradictions arising out of children discovering things for themselves and the counterintuitive nature of science, where everyday observations do not lead to accepted answers (Wolpert, 2000). These experiences influenced a later career change, but the approaches also influenced my world view.

These experiences came at a time of greater change, where ‘schools and teachers were affected more and more by the contingencies of an increasingly complex and fast paced modern world’ (Hargreaves, 1994, p.17). Schools began to have science subject leaders, a role I undertook, and I was being trained to teach science in a particular way (Keogh and Naylor, 1996). My early understanding of teaching science was informed by Piagetian thinking, although my approach can be crystallised into a belief that science generally was something that small children could accept and enjoy. As a result, the infants in my care were taught about the Pleistocene age, as dinosaurs were something that excited them. They learnt how fossils were formed and made some out of plaster of Paris. We had displays about rocks and talks by people whose job it was to find oil. Retrospectively I question why I ever thought infants needed to know about time epochs, or how I justified this approach with my belief that children liked big words. Through the SPACE project I became aware that children had individual ideas and I contributed to the 'mountain of examples of children's alternative conceptions' (Claxton, 1986, p.126). Yet I also held the belief that children would not know the correct scientific things if they had not been taught. I saw my role as providing the children with activities, so they did not need to discover things alone. The following quote by a science educator, prior to primary science taking on its 'field' (Bourdieu, 1990), exemplifies my position, where teaching by rote was acceptable:

> The whole point of discoveries is that once they are made everyone can share in them without having to repeat the process of discovery. Life is too short for each child to rediscover all of science. Likewise, to argue that children should be active does not mean that they should be active all the time. Some science facts have to be learned by rote and without complete understanding. (Elkind, 1972, p. 9)

Elkind's position is not the view held by the constructivists but learning by rote is part of the way everyday knowledge is learnt (Plotkin, 1997) and can contribute to a child's understanding of everyday life (see section 4.3.1). By the late 1980s the field of primary science had changed significantly and this field, or occupied social space (Bourdieu, 1984), went on to influence what science educators believed. This field organised the activity, but the activity was also influenced by the field.

I found it empowering to be part of a research project and the fact that the children's drawings and ideas were unscientific, and amusing made this a stimulating process. I also enjoyed talking to other teachers who had an interest in science. The work was published as teaching materials (Nuffield Primary Science, 1996a and 1996b), with handbooks for science leaders (Nuffield Primary Science, 1996) and was used by many teachers across the UK. Below is a reflection on the process, written for initial teacher trainees:

> A tank of water was placed in the classroom and the children were asked to record the water level by marking the outside of the tank with a permanent marker, every couple of days. At the end of the two weeks they noticed that the water level had dropped, and they were asked to draw what they thought had happened to this missing water. Unfortunately, no taught knowledge of the water cycle was in evidence in their responses. The children drew pictures that included mice drinking the water at night, the caretaker taking it to make coffee; there was even an idea of a hole in the bottom of the tank and an invisible line, leading to the radiator below the windowsill. Only one child, Russell, drew the sun with a straw sucking up the water. I was fascinated and thus began my immersion with a version of constructivist ideas of teaching.
>
> My reflection on constructivist science teaching (Ward, 2000)

The segment above describes my immersion in constructivist teaching when I discovered that children constructed their own ideas. It was important because I totally misconstrued the process at the time. This elicitation activity was one of the first activities from the SPACE project, and although I had taught the water cycle previously in a rote learning way (Elkind, 1972), I naïvely expected the children to have remembered what they had been taught (only a matter of weeks before). I wonder if the children had instead been asked to draw a water-cycle they would have been successful. However, the SPACE activities were targeted at what the children thought rather than what had been taught. Whilst it was easy to elicit the children's ideas, it was problematic to challenge the ideas of mice, coffee making and the imaginary line, as the research made no attempt to predict or prescribe what to do next with these uncovered ideas. The elicitation process became a mainstream part of primary science teaching, developing the field (Bourdieu, 1990) and influencing the practice of qualified and student teachers.

1.3.4 Constructivist teaching

Whist I enjoyed such elicitation activities my practice in the classroom was very disjointed. The children's ideas stage was a new experience, but this was then followed by processes such as observing phenomena and then generalising to provide an explanation. The children would generate interesting ideas, - for example, that inside an egg the chick was already there but in small pieces that would be stuck together as it grew, or that light behaved like a cloud of dots, rather than straight lines. My inductive approach to science fitted with this method perfectly because I accepted that science started from observations leading to scientific realism. However, the children were also encouraged to share their ideas, and as Tudge (1990) established, this resulted in some children causing their classmates, to regress in their thinking. This inductive reasoning approach corresponded to how I now remembered the sciences as operating and is found in the stories told in science education, for example: 'Charles Darwin caught many finches on the Galapagos Islands. He later noticed that the shapes of the birds' beaks were different on each island. After studying the beaks, he concluded that each shape seemed to serve a purpose suited to the conditions on a particular island' (Lee, 2000, p.15, cited by Lawson, 2004, p.317). This is a simplified version of the events that took Darwin forty years to develop, (Darwin, 1859) which endorses a 'miracle of science' approach.

Retrospectively, I can identify problems with my teaching: my pedagogical skills were limited, and I viewed children's ideas as opportunities for theories to be eliminated rather than an opportunity for discussion of possibilities (Roby, 1988). Also, my personal understanding was limited to a Newtonian approach to physics and my understanding of the nature of science was the cumulative success story, or the 'legend' (Kitcher, 1993). I followed the prescribed approach to find out children's ideas but then taught the science that I thought pupils should know using my prior understanding. It appears this was common with teachers, like me, carrying out '[t]he simple application of instructional strategies in which the teacher is the principle actor and the students are objects upon whom action is taken' (Windschitl, 2002. p.131). However, the SPACE approach was always going to be challenging when children's ideas of dots and clouds of light had to be tested in a classroom to demonstrate how light travels.

My involvement in the SPACE project led to promotion and I became part of the management team in a new larger school. The headteacher encouraged me to enrol on a master's degree in 'management and marketing' at a university in Manchester. I began to spend one day a week outside school finding out about the wider world outside of education. Although I continued to enjoy teaching science, I grew further and further away from science; until life changed and I found myself seconded to the Local Authority as a primary science AT.

1.3.5. Becoming an Advisory Teacher

Becoming an AT was the most challenging but most exciting time of my career. From a Bourdieusian perspective, this fork (Bourdieu, 1990) took me away from school management. After being outside the confines of a classroom for at least one day a week for two years, I did not want to return to the same role, so I had applied for a range of positions, one of which was a secondment to the advisory service. The path that I followed could be viewed as serendipitous, but all the choices made were also influenced by the context and the possibilities. The selected path went onto shape my behaviour, but my behaviour was instrumental in identifying the path that seemed possible (Bourdieu, 1990). The science qualification and the work with the SPACE team made my skill set suitable for the role of AT; my 'evolving habituses' (Bourdieu, 1990) formed by this role as an AT were to further shape my understanding of primary science. This evolving field of primary science influenced, and was influenced by, the role I was taking (Bourdieu, 1990). I had thought I understood science, so I had applied for the role; however, in the first six months it became apparent how little I knew about primary science teaching.

The induction into this new role again was another time of 'persuasion and pedagogy' (Kuhn, 1962) where my role was to ensure teachers accepted an approved version of science. This approach required an understanding of what was important about science from the perspective of primary science educators already in post. As a result, whilst I learnt a great deal, I promoted one sort of knowledge - 'science as a finished achievement' (Kuhn, 1962, p.1). This is a view I would now identify as a false view of science that is as fictitious as 'an image of a national culture drawn from a tourist brochure' (Kuhn, 1962, p.1). An idealised notion of science informed my understanding of primary science, something that is also found in some of the biographical chapters that follow (Chapters 7 and 8). Induction into this new role was through an apprenticeship and mastery of the tradition (Latour and Woolgar, 1979; Bourdieu, 2004). I was developing my symbolic capital through 'the pedagogic work with inculcation of the "strict rules" to the point that they acquired an embodied form' (Bourdieu 1990, cited by Moore, 2008, p.109). My role was to deliver a set of pre-written training courses and to convince others to adopt these strategies. By the time I was permitted to write any course material the approaches and ideas were heavily influenced by my experienced colleagues with scientific realism as the message.

This role of others influencing the knowledge creation system was found in other research (Harland and Kirkland, 1992; Martin, Russ and Bishop, 2000). Martin, Russ, and Bishop (2000) trained ATs in Africa and categorised their work as a process of 'envisioning', where these ATs adopted the promoted ways of working which, according to Martin *et al.* (2000), were not didactic. Yet in order to be considered as successful at the end of the training, these ATs had to adopt the 'rules of the game' (Bourdieu, 1990) as laid down by the training provider. In line with Martin *et al.*'s (2000) research, the AT training I received affected both my behaviour and my worldview, I accepted the dominant narrative that teachers lacked scientific knowledge and my role was to provide support alongside practical tasks for their children. Working collegiately creates a collaborative culture but also results in the loss of individualism (Hargreaves, 2004, p.17). If an approach to teaching is being promoted, this loss of individualism may be viewed as an advantage if the outcome is the adoption of set approaches. Bourdieu also identified that the longer actors are immersed within the field, the more they gain a feel for the game, the 'practical mastery' (Bourdieu, 1990) that comes from working with others within the field.

Whilst my feel for the game was never perfect, the prolonged immersion into the practice and rules of the situation enabled me to recreate new training materials on established lines. My role was to send teachers away back to their rectangular boxes (Gruber, 1986), feeling they could use the recommended primary focused scientific enquiry activities and that there would be a match between these approaches and the teachers' wider views of effective teaching (Kinder and Harland, 1992). However, it could be said that the walls of these rectangular boxes were beginning to tremble.

The longer I was an AT the less aware I became of other elements of primary practice. My view of the game, as one of the players, was not the same as the teachers' spectator view. As one of the players I had lost the spectator view that I had previously held. I also needed to understand how teacher/spectators who were not ATs might have a different view of primary science and how to support them effectively to change from a secondary science teaching experience to accept the narrative of the 'child as scientist'. I was no longer using science from my degree or prior teaching but instead was adopting these new approaches of primary science. The habitus of an AT was acquired and became part of my permanent disposition, and the principles underlying the training that I now delivered to others reinforced the principles and disposition that I held (Bourdieu, 1990). In these times of 'envisioning' (Martin *et al.*, 2000), I developed an understanding of the ways of working and became like 'a fish in water'. As I became more experienced, I was able to use the 'doxa', or the unwritten rules of the game, the 'subjective expectations of objective probabilities' (Bourdieu, 1990, p.59). I continued working in this role, extending my symbolic capital by building a national reputation, running courses outside my local authority until 1996 when I moved with my family to take up another AT role in the South of England.

1.3.6 A change of location but not of perspective

My highly developed science 'doxa' accompanied me to this new role and I became the experienced AT who supported a less experienced colleague, who happened to be my line manager. This change from an established post in one large Local Authority as part of a team of three science ATs, to a new post in a different Local Authority, caused some hysteresis (Bourdieu, 1984). I was the only science AT within the new Authority that was also undergoing structural change and lacked the development of my previous Authority. I associated this time with Bourdieu's term 'hysteresis', which describes changes in social systems over time, linked to the ancient science ideas of elastic limits where things change and do not go back to the original shape or place. It can also be thought of as a mismatch between two elements that had previously been coordinated, or a change that is permanent and irreversible. Although the elastic was stretched at this time it never reached breaking point. In this new role I created a scheme of work for all schools within the authority to follow and began working with the curriculum agencies who were writing national science schemes of work (QCA, 1998). I was also invited to work with the BBC on their SATs revision programmes, 'Revise-wise', and then with the development of materials on prehistoric animals called 'Walking with Beasts'.

However, a greater hysteresis was approaching with the election of New Labour (1997) and one of the changing foci of education was that primary science became less important. The introduction of the National Strategies focused only upon the newly termed literacy and numeracy (1998). Hardy (2014) suggests that this was an example of field change in primary education, as government and administration imposed new pedagogical processes.

1.3.7. The Hysteresis and field change

After a decade of the National Curriculum the introduction of the strategies in education in 1998/9, (DfES, 1999) initially affected my role within the Local Authority only slightly. Bourdieu identified that at times of social and personal stability, changes can occur slowly and as people are suited to their environment, the field and habitus is well matched, so the change can appear to be slow even when the change is catastrophic (Bourdieu, 2000). In primary science education, state interventions changed the field: although science was a core subject it was not a 'strategy' subject in primary schools and the introduction of these set ways of teaching in the other core subjects resulted in science having lower status. Over time these changes caused disruptions between the habitus and the field and as a result there were also changes in symbolic capital for many science ATs, who found themselves side-lined. My role changed to include National Test security arrangements, and by 2000 I had moved from Local Authority work to a science role in a university.

Advisory Teachers for English and Mathematics benefitted from the field change and were renamed as literacy and numeracy consultants. In contrast primary science was '[e]roded by falling status, undermined by national strategies, and finally put out of its misery by the ending of the Key Stage 2 science SAT' (Stringer, 2010a, p.12). The field changes resulted in a loss of position, power, and economic opportunities, although my belief in a certain way of teaching science - my 'doxa' - remained. I was not alone in viewing these times unfavourably, with Turner (2010, p.10) identifying the 'decade long tyranny of the literacy and numeracy strategies' disturbing primary science. The fate of primary science has remained uncertain and there has been continued despondency over 'sponge painting of mini-beasts and calling this science' (Stringer, 2010b, p.14). The hysteresis was real and felt by many.

My new university position was within a different type of field, with different regulations and expectations (Teacher Training Agency, 1997). Whilst the structure of my life at this time changed rapidly, the dispositions took longer to adapt, and I spent time carving out a role and position in line with my previous experience. As a result, there was a necessity to revaluate my symbolic capital and sources of legitimacy, which in hindsight took more than seven years of adaptation. I still worked on projects for the Wellcome Trust, the BBC, and other bodies, but the day job was harder to acclimatise to, so it felt that Bourdieu (2000) was correct that dispositions take longer to adapt. As will become clearer with the stories of other science educators, individual social practices are seldom determined by rules but instead are negotiated according to personal circumstances. As a science educator I have an interest in the field and this encouraged me to act in a 'particular way'.

The ‘doxa’, the way I thought primary science should be taught, remained stable throughout all these external changes, until I stepped out of my role and started to question everything I knew.

1.3.8. Summary

I selected science subjects because I achieved higher grades in these subjects. This in turn led to me accepting scientific answers to observations of the world. My disposition and presuppositions were strengthened as I studied science at university and when I became a teacher; I adopted strategies that, promoted a ‘particular understanding’ of science. I enjoyed discovering the children’s ideas about the world but was left utilising a ‘bricolage approach’ because the answers to some of the questions six-year olds raised could not be found practically. My role as an AT was only required because of the dominant narrative that primary teachers lacked skills and scientific understanding and that training would fill this gap. As an AT I also accepted the paradigm for primary science that stated poor teacher subject knowledge and confidence was leading to poor pupil perceptions of science but now, with hindsight, I question my simplistic notions.

Teaching primary science involves contradictions between eliciting children’s ideas about their world and requiring them to discover scientific facts using everyday observations which often cannot lead to accepted scientific answers. I never questioned that there might be more than one way to view the world, my habitus was formed by a scientific worldview and I tried to bring learners to this perspective. This was all to change when I spent two weeks in Turkey on a methodological course where I met people who did not hold a science worldview and who questioned scientific realism. As a result of attending this programme I made the decision to evaluate primary science using an auto/biographical approach. This decision resulted in the changed to my epistemological and ontological approaches that were discussed at the start of this chapter. I end this work as a critical realist rather than the positivistic science educator who accepted uncritically the dominate narratives of primary science education. Reaching this critical realist position required reflection on how culture had influenced my beliefs. In the next chapter I will share what I learnt about the dominant narrative of primary science from literature and reports.

Chapter 2: Teaching primary science: the role of narrative, attitudes, confidence and beliefs

> Why do we spend so much of our time telling one another stories that neither side believes? (Boyd, 2010, p.129).

2. Introduction

This chapter aims to set the study of science within the larger structure of narratives, the narrative of science is not just the unresolved story of primary science teacher confidence. In this chapter I link the narratives to the theory of how learning happens and alluding to the evolutionary traits that make telling stories an important part of cognition. I am going to begin to address the first research question concerning the paradigm for primary science by considering this narrative, and how far it is based on evidence. After outlining the reasons for accepting narratives as a way of knowing, I will then examine beliefs and why some beliefs are held and end this chapter with the attitudes surrounding the narratives of primary science as told by research. These themes emerge again to gain in the case studies that will follow. I suggest this approach is useful because it provides a variety of different perspectives.

2.1 Narratives as a way of knowing

Stories can stir the emotions and both fact and fiction consolidate behaviour, communicate norms, and provide a social function. Telling stories, like honey bees dancing, is adaptive behaviour and is time consuming and uses resources that otherwise could have been saved (Hansen, 1999), but it provides advantages. One advantage is how narratives can contribute to group living and deliver evolutionary advantage as social species prosper better together than alone (Boyd, 2010). Narratives are a method for understanding patterns in nature and are a way of communicating information. Stories enable human minds to test scenarios, possible actions and their consequences (Pinker, 1997) and practices of modern hunter-gatherer societies suggest that stories are used to maintain group structure and for communicating social norms (Boehm, 1993). Storytelling in larger group situations enables information to be exchanged about both challenges and opportunities and human evolution has utilised these social elements and become ultra-social, creating settlements that contain millions of inhabitants. Humans are the only living organisms whose adaptive capacity is primarily a learned one (Hurd, 1997).

Narratives are useful in the sciences and scientific discoveries or inventions are often recounted as stories. Some have been later found to be imaginary, such as 'Piltdown Man'; others, such as phlogiston or the morning star, which met the requirements of scientific practice of their time, have since been retold with different outcomes. This tentative nature of knowledge occurs in all domains not just science. The human desire for stories and the human need for pattern are connected to human cognitive development (Boyd, 2010). This pattern making often begins with observations but when humans imagine a picture or think back to a place, they have visited they create an image very different from the construction of a photograph. A photograph records details that the person looking through the viewfinder is unaware of and if a computer stores the digital picture it will consist of more than 1 million pixels (Du Sautoy, 2016, p. 346). The human mind takes the image and creates a story, adding or removing information often to suit an existing narrative (ibid). This is something a computer currently cannot do, as computers cannot use the information to narrate outcomes. The human mind can also regenerate that picture at any time of its choosing, and this ability is a measure of consciousness (Du Sautoy, 2016). Narratives are an integral way in which humans understand all aspects of their world. They play an important role in all types of thinking and the ability to create stories enables humans to plan for their future. Scientists use narratives because 'narrative is how the relationships amongst their materials become known to them' (Morgan and Hirschman, 2017, p. 2).

Stories have common features: they contain agents, actions, characters and plots mingled with the intentions of these agents. Bruner proposed that there must be the agent who undertakes the action, and that this action should be directed towards goals controlled by these agents. The outcomes are part of the prominent pattern in stories, as stories of all kinds are representative structures which are 'not taught but instead reflect our mode of understanding' (Boyd, 2010, p.131). This understanding of structure is not unique to fiction: in *Acts of Meaning*, Bruner identified 'the kinship or affinity between 'fictional and 'empirical narrative' (1990, p.52), later suggesting that, through narrative, people are liberated from human frailty to construct 'possible worlds' that their cultures enable them to imagine (Bruner, 2012, p.6). Yet these same cultures constrain what humans can do, and what is possible, by both structure and law, binding humans to social conventions. There is a tension between what is possible, but which society deems illegal, and 'what is conventional and boring' (Bruner, 2012).

There are also levels within narratives, there is a dominant narrative that endures over time and is known by all members of a culture, (Richardson, 1990; Glover, 2003) at an individual level there is the personal narrative (Glover, 2003) (chapter 6, 7 8 and 9). There are also local narratives that place the dominant narrative within a contemporary setting to create powerful influences at both social and cultural levels (Glover, 2003).

In all story telling there is also an element of the anticipated, where the personal is linked to a dominant narrative. Bruner reflected on some of his earliest experiments on perception, identifying how the length of exposure to pictures or words affected the human ability to guess the word or picture. Bruner (2016) recognised that people were able to make guesses with very brief exposure time but, even with extending exposure, their first thoughts influenced their later guesses: they were 'victims of their own previous conventionalizing efforts' (2012, p.8), suggesting humans expect certain events and like stability and convention. 'Conventionalizing efforts' will appear later in the science educators narratives. Situations influence what can be expected and there is always a compromise between the established and the possible. Bruner used real and made up words, as well as pictures, included what he termed 'dirty' words and 'lewd' pictures. He found that dirty words (and lewd pictures) took much longer for people to recognize than conventionally 'proper' ones (Bruner, 2012, p.8) because people do not expect to be shown rude words or pictures in such test situations. The established and the possible are heavily shaped by the realm of narrative thinking and are how a 'culture's narrative forms become incorporated into our individual ways of conceiving of the world' (Bruner, 2006, p.10). Only one lewd word is found in the case studies that follow, but as will be made clearer, these science educators are influenced by the conventionalizing efforts of the published narratives of primary science.

2.2 The Value of Narrative

Narratives are valuable because 'people do not deal with the world event by event'; instead, they put segments together and these provide 'interpretive contexts' (Bruner, 1990, p.64). In *Making Sense* (1987), Bruner identified that 'our sensitivity to narrative provides the major link between our own sense of self and our sense of others in the social world around us' (Bruner 1987, p.94). The biographies of the successful science educators demonstrate clearly the participants' sense of self as they retell the dominant narratives such as the child as 'little scientist' learning through play, the 'P.E. teacher lacking in confidence' or the 'Primary Teacher with misconceptions of science'.

Narratives are not just simple rules, and, in order to learn what is culturally and socially acceptable, require an understanding of the whole picture, not just the problem, and why the problem is important. The problem in primary science has revolved around a dominant narrative of confidence: 'the string of studies showing a general lack of confidence among teachers in science 96' (The Royal Society 2010, p.82). These dominant narrative influences many of the behaviours within primary science and will be examined in a range of ways within this thesis, from the published research. Narratives are built on belief systems and therefore an examination of beliefs and why they are held is discussed next.

2.3 Beliefs

In order to believe, assert and act upon the dominant narrative that science teachers lack confidence and scientific understanding, or that, in fact, they do not, a belief must be held. Such a belief is only possible if, and only if, I am in a position to know this: that I am justified to hold this belief (Smithies, 2012). Centring on the Knowledge (k) rule (Smithies, 2012), a justified belief can only be asserted if I am able to know. So, the specific issue of scientific knowledge and confidence in primary science revolves around what counts as being able to know, and 'what is true?'

The idea of 'Truth,' was discussed in the introduction, as an ideal and it might be more effective to think in terms of confirmation (Longino, 2002, p.115). For there to be scientific facts that are accepted, this information should conform to real life. Yet in attempting to make justifications, assumptions are always made and are subject to prejudices, wishful thinking, and ideologies. Therefore, it is helpful to examine why beliefs are held.

2.3.1 The reason beliefs are held

My belief systems, or *living theory* (Whitehead, 1989) changed after gaining a different perspective which led me to question whether my previous the beliefs were correct epistemic assertions, or pragmatic ones. The participants within this study also hold presuppositions which inform the way they consider science education should be taught. Beliefs are not direct entities and there are pragmatic and epistemic reasons for holding particular beliefs. It is also known that justification for a belief can be altered – for example, if 'Dr Evil' threatens dire consequences if a particular assertion is made (Crisp, 2005). In primary science education, 'Dr Evil' may be represented by a learned society, or the Department for Education, or Ofsted inspections, as will be shown in the participants' life stories that follow. Questioning certain beliefs might lead to the assertion that it is better not to ask, particularly if the science education community at large embraces that belief. As a result, a personal justification for a belief could be insufficient and a pragmatic approach would assert that this is known (p) (Smithies, 2012) and to challenge such a thing would be against a common-sense view.

Beliefs, though, are complex and are subject to personal taste, as was shown by Feynman (1967) when discussing the three different laws of gravitational attraction:

> It is impossible to make a decision, because there is no experimental way to distinguish between them if all the consequences are the same. But psychologically they are very different in two ways. Firstly, philosophically you either like them or do not like them, and training is the only way to beat that disease. Secondly, psychologically they are very different because they are completely inequivalent when you are trying to guess new laws. (Feynman, 1967, p.53)

Only one of the science educators in this study would recognise this aspect of physics, that physics is incomplete and therefore there is a need to guess (Feynman, 1967). For the rest Newton's gravitational laws are the belief system in place and guessing would not be considered scientific. Their beliefs emphasise science as the absolute conception of how the world is rather than this being merely the currently accepted way (Hacking, 1983). Most of the participants held a belief of absolute science that can be communicated to others. Peter is the exception, as the incompleteness of physics is what involved him in science initially [Chapter 9]. The irony is that the dominant narrative that teachers lack scientific understanding and therefore confidence revolves around scientific facts that are often no longer accepted by scientists.

This issue is central to this thesis as my belief in science and what I ought to believe was questioned as I examined if teachers really lacked scientific understanding, leading me to question what is 'being able to know'? That introduces a psychological dimension to the discussion. As Feynman identified, it is possible to hold a belief – for example, about gravity – but for that belief to be based on incorrect information and as a result, something is accepted which is untrue. This Justification Knowledge (JK) rule revolves around the question of 'how can you know …?' or 'how do you know that …' The answer for each person depends on the narrative they accept, and this presupposition then informs future practice. As this study unfolds several personal narratives are unearthed which become an adaptation of the dominant narrative: some relate to understanding and confidence of teachers, and some relate to who should experience primary science, whilst others focus on the aims of primary science education.

It is plausible to assert that teachers lack confidence because they lack scientific understanding, even if those asserting such a thing may not be in a position to know, and may base their ideas on limited evidence, and not 'what actually happens in classrooms' (Beggs and Murphy, 2005, p.121). If lack of understanding of scientific understanding leads to lack of confidence is a 'known' fact then this becomes probable, particularly if it seems credible to be able to link the lack of confidence with the lack of knowledge (Sharp and Grace, 2004). The more often this narrative is asserted, on the bounds of probability, the more it turns it into a justified belief. This dominant narrative, however, will have an impact upon the future actions of primary teachers as well as these successful science educators.

2.3.2 Future actions

Holding a particular belief is found to influence future actions (Bratman, 1987). If primary science teachers lack scientific understanding, educators will take this 'fact' for granted and will not plan for any other action to address this. In such circumstances there is no need to give any thought to questioning this belief. I personally did not question this belief, taking reported information at face value, never examining the foundations of this dominant narrative, never interrogating the research or challenging the methodology or the sources. It was part of my training as an AT to know that teachers had a limited understanding of science.

Lack of questioning is typical human behaviour (Smithies, 2012), which explains why in the past there was a belief that the world was flat, and that light travelled only in waves. These were the views of common knowledge; the view of society. They were known facts and the community justified these beliefs, believing them to be true. However, different evidence has been shared concerning the shape of the world, for example a spherical Earth is shown nightly on the evening news! Holding a belief affects both planning and action and the amount of planning directly relates to commitment to the idea that is currently held (Bratman, 1987). If there is strong commitment to a belief that is accepted by society- it becomes true - there is no need to question, and nothing else needs to be planned. Humans are programmed to behave like this because of cognitive limitations, because it is too difficult to keep track of the 'changing strengths of all our credence and preference over time' (Smithies, 2012, p.278). By selecting a dominant narrative, the space of options needed to be considered is reduced, just as tacit knowledge in science is accepted without having to go back to the elements of fundamental knowledge. The knowledge exists; belief in its existence has been proved and it becomes the foundations for further understanding (Hacking, 1983). Hacking suggests that this is the doctrine of scientific realism, where physics aims at the 'truth' and if it succeeds, it is the 'truth'. However, there are always grey areas to consider and these will be discussed next.

2.3.3 Context-relative acceptance: a 'story of science'

Humans occasionally, for pragmatic reasons, hold a belief to be true that is not true. These 'grey areas', or 'context-relative acceptance' are where there is a practical reason to accept something as true whilst a belief in this truth is not held (Bratman, 1987). In primary science this practical reason could be owing to a special interest of professional institutions – it could be related to funding, or to a wish to continue a 'narrative of science' for political or personal gain. The issue of lack of teacher understanding of science is a belief espoused by the Royal Society of Chemistry (RSC) who published the following:

> The National Audit Office (NAO) confirms that teaching is of better quality where secondary chemistry and primary science teachers hold qualifications in the subjects they teach. (RSC, 2014, p.4)

This appears to make the common-sense case that teaching is better with a qualification. This report is about science teaching, which suggests that the statement is also about the science subjects. In fact, a search of the NAO document cited by the RSC using the term ‘primary science’ produced no matches. There are four inclusions of the term primary within the NAO document, but these all relate to primary mathematics.

However, the NAO document does demonstrate that support for teachers’ development is worth a great deal of money: with £35 million being spent on science and mathematics support. However, they did not find a direct causal link between the money spent and outcomes. Whilst the evidence is concentrated within secondary education, at no time does the NAO propose a causal link between knowledge of science and confidence. This leads to a question about the acceptance of such beliefs and the continuation of this dominant narrative.

In science, there are theories that are known to be untrue, but they are useful in making predictions about the world, so they are accepted and are continued to be used. These underdetermined theories have been a common feature of the history of science (Kuhn, 1962). It is known that whilst belief is sensitive to evidence, acceptance is sensitive to practical considerations (Smithies, 2012). In primary science education, there could be a question about whether the standards for research are less stringent, or if those who peer assess publications accept the bigger picture of underachievement and lack of skill and therefore keep this agenda in the forefront of the public agenda. However, the NAO is also not without evidence of acceptance, as they state that many pupils who could follow a science career have rejected this option by the age of 16 (NAO, 2010). The statement about pupils following a science-related career is a dominant narrative in secondary schools, particularly if there is an economic reason for teaching science, although American-based research suggested that more students transferred into STEM based courses than transferred out, and as a result the STEM shortage is a misnomer (Salzman, Kuehn and Lindsay, 2013). As identified above (section 2.2) narratives provide a link between self and others (Bruner, 1987). Justine’s biography provides evidence for this not being only an American phenomenon and requires some reflection on what is known about narrative of the pipeline.

2.3.4 The narrative of the pipeline

As identified in the introduction one role of science education, including primary science as a way of ensuring enough future scientists. This is a phenomenon known as ‘the pipeline’. If government accepts that teachers lack an understanding of science, skills, confidence etc., and the stakes are high, then it is harder to contemplate that this is unlikely and as a result this belief is strengthened. The pipeline narrative is persuasive - The Royal Society of Chemistry document starts with a statement about why currently there is an issue:

> Science underpins growth sectors across the country and is a central driver of and contributor to the British economy. Yet too many young people are missing out on job opportunities in these sectors because of a lack of science and chemistry skills. Chemistry-using businesses are currently left searching for employees: by 2020, the shortfalls in apprentices and graduates are estimated to be 12,000 and 19,000 respectively. (RSC, 2014, p.1)

This is a persuasive argument, yet the Advanced Resource Managers (2016) reported that less than a third of graduates with a STEM qualification were working in a STEM field, lower than the number a decade before (ARM White Paper, 2016, p.3). The reason given was the mismatch between the STEM graduates' career aspirations and what was being offered by the STEM companies. ARM reported that 'the skill shortage is created by the employers being too inward focused' (2016, p.8) rather than there being a shortage of graduates. Yet this is not acknowledged in the education literature which focuses on the lack of Scientists because primary teachers have limited science qualifications:

> A Wellcome Trust survey of a sample of primary schools found that worryingly 17% of science subject-leaders have no science qualifications higher than GCSE level. (RSC, 2014, p1)

Therefore, statistically, 83% do have science qualifications above GCSE level, which is a great improvement on previous figures (POST 88, 1996), although the size of the survey is unclear. To re-enforce the dominant narrative the term 'worryingly' was used, and on the same page, negative comparisons were made between UK and countries that the RSC (2014) suggested did better than the UK because they employ specialist teachers. The local narrative links teacher understanding of science, future opportunities for pupils and subject specialist teachers. One of the countries used in the RSC (2014) report was Poland. Closer examination of the OECD data (2015) comparing Poland with the UK does not support the RSC's interpretation as the mean score (PISA, 2015) for science was 509 for the UK compared to 501 for Poland. The share of top performance in at least 1 subject was 16.9% for UK compared to 15.8% for Poland, (OECD, 2016, p.12). I question if a local narrative is influencing research and whether questions should be raised about professional institutions' motivations.

In the biographies that follow personal interpretations of issues in primary science education are provided, although, as shown by the RSC data above, commitment to and acceptance of a dominant narrative make beliefs hard to change. Context also plays a part in belief formation: if a belief is generally accepted, then in conferences and professional settings, for example, to question the dominant narrative may be too difficult, particularly one which seems to be based upon common sense. As such, beliefs are sustained and justified, as Reynold identified, 'justification is what knowledge looks like from the inside' (2002, p.151). The biographies illuminate the presuppositions and motivations of these successful science educators. The literature on the dominant narrative of primary science is illuminating and is discussed next.

2.4 Narrative in primary science research

In order to examine the '*unitas multiplex'* (Feldman, 2005, p.5*)* behind teaching primary science, and the issues and concerns expressed in publications such as *The Royal Society Report* (2010), I decided to try to gain access not just to the agents but also to the settings and action. To reach the start of the story, I began by following the trail within footnote 96 of the quotation above, which read 'For a review, see Harlen (2008b)'. This led to an archived report *'*Perspectives on Education 1: Primary science' by the Wellcome Trust, 2008, where the expected information on 'the string of studies' was absent. In its place was a history of primary science curriculum development, and a suggestion that there was a 'low level of content knowledge of the majority of primary teachers' which resulted in the development of a

> National training programme which, along with increased attention, some publications and some non-statutory guidance had led to increased competence in primary science. (Wellcome Trust, 2008, p.10)

As this did not equate to 'a string of studies', I returned to primary sources. The Wellcome report concluded that for primary science to be effective there was a requirement for 'teachers who themselves understand "how science works"' (Wellcome Trust, 2008, p.14). I began to question if the dominant narrative of primary science were guiding appropriate behaviour, the outcome of which was an interpretation that told of the lack of confidence and in some cases the need for specialist teachers (The Royal Society, 2010; RSC, 2014). So, I began to question whether the culture of primary science was being perpetuated by a dominant narrative which existed like chains of images linked together through collective stories of coherence, likelihood and logic (Rosaldo, cited by Bruner, 1987) that were not, however, supported by evidence.

2.4.1 Investigating confidence further

To examine the *verisimilitude* of the story I used Library Search and the terms 'Primary Science' AND 'Confidence' and more than 18,000 items were generated, from this a list of 338 peer-reviewed journal articles that were closely related to the topic was identified. A number of these documents were then discounted as they contained no clear methodology and therefore their validity could not be interrogated. 43 papers were then examined in depth; of these only 16 were focused on qualified primary teachers instead of pre-service teachers and only eight were based in the UK. All 43 were used to inform this work. In addition, reports by professional bodies, such as The Royal Society, The Royal Society of Chemistry, The Institute of Physics, The National Audit Office, The Welcome Trust, Ofsted and government policy documents, and reports by the CBI or HMI, were also accessed. This chapter and those that follow will utilise these documents but because attitudes and attitudinal surveys into scientific understanding and confidence of primary teachers were a main theme of many reports and research papers, the issues concerning attitudinal surveys will be addressed first.

2.4.2 Attitudes and how to measure them

The measurement of attitudes has a limited history: before the 1920s it had been thought to be 'impossible to measure attitudes' (Reid, 2006, p.3) or that attitudes were obsolete as a scientific construct (Wicker, 1969 cited by Kraus, 1995). Today, attitudes like confidence are commonly accepted and are often measured using Likert scales. Likert scales (1932) were initially based on questions using a five-or seven-point scale and based on the premise that attitudes guide and shape future behaviour (Allport, 1935). The evidence that stated attitudes are not always consistent with behaviour (Kraus, 1995) does not seem to be a premise that features highly in attitudinal research in primary science.

The understanding of attitudes as a complex conception has more recently gained recognition; with Reid (2006) identifying that one of the major issues with attitudinal surveys is the perception of what is being measured. The evaluation of attitudes requires: a cognitive aspect - knowing about the area in question; an affective element - the respondents' likes or dislikes; and a behavioural aspect - what might happen as a result of their affective stance (Van Aaldereen-smeet *et al.*, 2012). There is now a realisation that there is some ambiguity with the concept of attitude to science, as it can refer to 'a variety of thoughts, values, and feelings about science and science teaching' (Van Aaldereen-smeet *et al.*, 2015, p.712). It has also been found that there are also differences for teachers with regards to their professional and personal attitudes to science (Van Aaldereen-smeet *et al.*, 2012) as well as their attitudes towards specific aspects of learning within the different sciences – for example, attitudes towards biology as opposed to physics. Only some of these factors are included in earlier attitudinal studies in primary science teaching. Students are found to have attitudes that are still developing or are based on limited information (Sears, 1986; Aikenhead and Ryan, 1992), which is also important if the results of pupil attitudinal surveys are to be considered meaningful.

Measuring attitudes is undertaken by asking questions about the likelihood of a person thinking or acting in a certain way – for example, being able to picture oneself in a science-based career at 30, a question in the PISA data collection (OECD, 2006; Kjærnsli and Lie, 2011). However, regardless of whether the questions measure current or future attitudes, attitudes are latent constructs, subject to issues of self-reporting which can only be inferred, so 'attitudes cannot be measured in any absolute sense' (Reid, 2006, p.11.) However, before and after comparisons for the same individuals using the same questions can provide insight.

Another concern with some earlier research on attitudes upon which the dominant narrative of primary science rests is the inherent problems of the scaled nature of the questionnaires used. When attitude constructs are scaled from 'strongly agree' (scale of five), to 'strongly disagree' (scale of one), and these numbers are then used to create an overall score, problems with both validity and reliability are caused (Reid, 2006). This is because respondents can be given the same overall score when their responses on each question could be very different resulting in participants with different profiles being considered identical. Another challenge to reliability and validity occurs when different types of questions are combined even though the questions are enquiring about very different aspects of scientific attitude. Therefore, the results might not be meaningful (Osborne *et al.*, 2003; Reid, 2006; Van Aaldereen-smeet *et al.*, 2012).

I have a personal concern about the suitability of some statements for specific age groups – for example, the statement that 'The government should spend more money on scientific research' using scale scores was asked of Year 6 pupils in Turner's and Ireson's (2010) study on pupil attitudes. My concern is the relevance of this statement for 10-11-year olds and is compounded by the fact that this study did not use the same questions pre- and post- testing, although the authors stated these were stable (Turner and Ireson, 2010, p.128.) The study did provide transparency concerning the questions utilised, whilst many studies do not. Attitudinal research underpins the dominant narrative of primary science and the following example demonstrates how one often cited study (Jarvis and Pell, 2004) can perpetuate problems: 'many primary teachers not only lacked confidence and competence to teach science, but they also possess an incomplete understanding of science concepts' (Smith, 2014, p.467 citing Jarvis and Pell, 2004). However, the way the original data on confidence in the Jarvis and Pell study was collected results in outcomes that were not statistically meaningful, due to a loss of detail and correlation issues (Reid, 2006). Smith appears unaware of these methodological issues and therefore continues to repeat the dominant narrative and does not discriminate between 'facts and beliefs'.

Attitudinal questions can provide some thought-provoking data, but by amalgamating results into numbers with statistical outcomes this rich data is often lost (Reid, 2006). The objects, rules and beliefs (Bruner, 1986) of primary science practice are consumed by the chains of images that have evolved to narrate the well-known tale. The examination of the dominant narrative of a lack of confidence among teachers of primary science will continue with a scrutiny of attitudes and the role of scientific enquiry.

2.5 Scientific attitudes and enquiry in primary science

The view that 'science enquiry offers the possibility of an enhanced engagement in science education' (Nesta, 2006, p. 13) placed a spotlight on attitudes and the link between these attitudes and the future Science, Technology, Engineering and Mathematics (STEM) population, termed SET at the time (Roberts, 2002). This focus on future skills shortage was reiterated in the Foreword of the Royal Society's 'State of the Nation' report by Lord Rees (2010) who made it clear that the role of science education is to close the STEM skills shortage gap. This economic argument was also the main driver of the latest National Curriculum for primary science (DfE, 2013).

The Royal Society (2010) suggested that it is pupils' attitudes towards science which determines future success, even though pupils' attitudes are not stable (Sears, 1986). This concentration on attitudes appears to be based an acceptance that attitudes, in the primary phase, have an influence on pupils' involvement in the subject in the later phases of education, providing the ever-needed students for 'the pipeline'. However, research into students' attitudes does not directly link with attainment; in fact, Fraser (1982, cited in the Royal Society report, 2010, p.66) concluded that the relationship between positive attitude and higher attainment was very weak and instead that teachers should focus on improving attainment. Martin (2010) identified that attitudes only partially overlap with academic self-concept and that it is academic self-concept which is the strongest predictor of outcome. Throughout the Royal Society report (2010) there is little mention of the science subject knowledge required by learners but instead a greater focus on the practical enquiry approaches:

> Science needs to be enquiry-based at all levels of education but teaching to the test together with its associated fact based approach to learning **misrepresents** how science works, and conflicts with children's natural curiosity and exploratory instincts. (The Royal Society, 2010, p 83, bold added)

I have concerns with this statement. The first is the term enquiry-based science, as it is unclear what this term means. The term inquiry is universally used, but regardless of the terminology, the approach is uncertain. Ireland, Watters, Lunn, Brownlee, and Lupton (2014), identified that teachers all use the enquiry term, but their practice was very different. The second issue is the clear suggestion that there is a way that 'science works' and that a fact-based approach conflicts with children's curiosity and exploratory instincts and, '**misrepresents** how science works'. Misrepresenting how science works is a value statement and an example of a possible mismatch between the nature of science in education, science in real life and the story or 'legend of science'

(Kitcher, 1993). This debate is longstanding, with The Association of Science Education's primary committee identifying a greater interest in learners developing an enquiring attitude of mind than in them gaining facts (ASE, 1963). This raises questions concerning the exact role of practical work and whether practical work is the road to theoretical understanding. However, practical work is theory laden, and observations are made as a result of what the scientific theory suggests is significant (Woolnough, 1991). This tension between subject knowledge and skills will be identified within all the biographies that follow.

The fascination with the idea of 'how science works' (Harlen, 2008 p.14; The Royal Society, 2010) provides a glimpse of the links in the chain of images within a particular narrative of the nature of science. Yet, the sciences work in many ways depending on the nature of the questions asked (Wolpert, 2000) so this image could be an example of the stereotypical views of the sciences within science education. Scientific enquiry appears problematic not least because of the different understandings of what it is. This leads to the final issue with the Royal Society quotation, concerning the narrative of 'children's natural curiosity and exploratory instincts' and the conflict of scientific subject knowledge acquisition with such an approach.

2.5.1 The narrative of curiosity

Enabling natural curiosity is one of the benefits attributed to primary science activity. Picturing the 'child as an 'active scientist' (Bruner, 1987, p.1) unleashes a narrative of the child who constructs tentative ideas about their world, reflects on their experiences, is able to interact with their environment, and as a result creates ever more complex thoughts, on their own. In this narrative there is no place for the role that cultural and historical contexts perform in learning (Bruner, 1987). A different narrative is established if the social context and the role of other adults are considered; then the child becomes the 'intelligent social operator coping with the world of the unknown' (Bruner, 1987, p.1).

The narrative of the active scientist is Piagetian in approach and relies upon the adoption of a position of Naive Realism, which Piaget espoused (Feldman, 1987, p.133). However, this narrative of acting like a scientist might be selected by a storyteller who holds a belief that practical activity develops children's ability to solve practical problems, particularly if this is how the narrator visualises the role of a scientist. This perception that practical work will teach scientific understanding is questioned by research findings that indicate that directed practical work appears not to enhance learners' appreciation of the methods of science or to increase learners' understanding of scientific knowledge (Woolnough, 1991). Conceivably it is the public perception of the scientists that is at fault, as the creation of scientific understanding for children and scientists is

very different from the image of a lone creator of facts. Additionally, this 'lone scientists' image fails to consider the influences that affect the development of understanding of scientific facts which is a complex process and will be discussed in Chapter 4.
The use of the expression 'exploratory instincts' (The Royal Society, 2010, p 83), was understood by successful science educators in very different ways (Chapters 6, 7, 8, and 9). In a research project called 'Science Education Worldwide', Morris (1990) established that texts about science teaching at primary age contained the common narrative of the child as active scientists. However, he suggested that this 'derived more from belief about the nature of children and how they develop' (Morris, 1990, p.39) than an understanding of what science was or how it should be taught. This focus on 'learning by doing' was common across many jurisdictions but the success of this approach was not based upon evidence from research (Morris, 1990). The 'exploratory instinct' narrative includes fostering curiosity and the link to positive attitudes, and is commonly held (Tymms, Bolden and Merrell, 2008). A 'known' fact, current theory, or science hegemony is that children enjoy practical science and learn better through this approach, although to date there is very little evidence to support that this enables greater learning (Hodson, 1991; Woolnough, 1991; Abrahams and Millar, 2008).

The narrative that 'a child best learns to swim by getting into water; likewise, a child best learns science by doing science' (Rillero, 1994, p.1) is questioned by Woolnough (1991), who identified that practical work could result in children stating 'I do and I get even more confused' instead of the old adage, 'I do and I understand'. Yet Woolnough advocates that practical work is about teachers proving the scientific answer and therefore the adage should be 'I do, and I *believe*' (Woolnough, 1991, p.182, italics added). The presupposition of scientific realism was a vital element for many of the successful science educators. The relevance of science to the individual and their enjoyment – even love, in some cases – was visible in the participants' biographical chapters. Most of these successful science educators identified the role of science in everyday life and the public attitudes to science will be examined next.

2.5.2 Relevance of science and attitudes

A link has been made between scientific attitudes and the economic development of a country. This link was first identified by The Relevance of Science Education (ROSE, 2003) project and aspects reinforced through more recent international comparisons (Kjærnsli and Lie, 2011) which revealed that in Columbia and Jordan, more than 50% of 15 years olds reported they envisaged themselves taking a science role at the age of thirty, compared to just over 20% of students from the United

Kingdom (p.136). The ROSE report found that in underdeveloped countries there is a stronger positive correlation to science, whilst in developed countries the trend is a negative one. Kjaernsli and Lie (2011, p. 124) suggest that these responses should be interpreted carefully as cultural factors can influence the responses. The ROSE report (Sjøberg and Schreiner, 2003) identified that there was little evidence that the public at large was uninterested in the sciences or that their interest in the sciences was waning. In fact, the interest in the sciences as judged by the number of science books purchased, the viewing of science media, and visits to science museums, supported their findings that there was no reduction in public interest in science. The researchers therefore concluded that the issue with attitudes to science was a school issue (Sjøberg and Schreiner, 2003, p.11).

Research suggests that science outside school is enjoyed because there is no need to provide right answers, so a trip to a museum is safe and zoos are thought to be 'relatively non-threatening places where the learning activities are voluntary and often self-directed (Miles and Tout, 1992 cited by Dove and Byrne, 2014, p. 325). Recent work suggests that home life (including such visits) plays a role in science vision (Archer *et al.*, 2012; De Witt *et al.*, 2013) and subsequent aspirations in science, yet Kjærnsli and Lie (2011) identified that home (a composite measure of cultural and economic capital) and science teaching (a composite measure of type of instruction) have a negligible effect (p.132). Ebong (2005), in a smaller study, supported the finding that parents did not have a significant influence on achievements in physics exams, finding teaching to be the main influence, so it appears that the situation is not clear cut. Self-concepts (being prepared and feeling able to do science) were found to influence students' perceptions of their future career choices (Kjærnsli and Lie, 2011) which support the Eccles and Wigfield (1995) propositions.

An intriguing feature about primary pupils' attitudes to science is that they have remained constant. The Performance Indicators in Primary Schools (PIPS) database showed a stability of attitudes between 1988 and 2010, during a time of immense science curriculum change. Yet the Royal Society report (2010) continues to make a positivistic link between how science is taught and attitudes as being a determining factor of importance. This is not supported by the pupils' data from the Pisa (2006) study (Kjærnsli and Lie, 2011) or the INSPIREs research (Archer et al, .2014). However, the wording used in the Royal Society report was couched in language that suggests a 'strong suggestion' or a 'contributory factor' rather than being a definite causal link. The dominant narratives of science education are weaved from statements like the one below:

> [H]owever, there is a strong suggestion that how science is taught, the knowledge of the teacher and the extent to which pupils are actively engaged in studying something of interest and relevance to them may be contributing factors in forming the attitudes of both girls and boys towards science and mathematics. (The Royal Society, 2010, p.70)

This statement embraces the methods, the knowledge of the teacher, what the pupils do, the context of the teaching, the motivational aspects, and the relevance of the activities. I would agree that these things are important but wonder what was not covered by this statement. The dominant narrative is based on the role of teacher knowledge in primary science and this is now considered.

2.6 The narrative of limited science knowledge

The previous section began with a quote about teacher confidence, and here the connection is examined further as teacher under-confidence is connected to limited subject knowledge:

> 'Further, the oft-reported under-confidence among teachers in teaching science is undoubtedly related to lack of science knowledge' (Beggs and Murphy, 2005, cited by The Royal Society, 2010, p.83)

The choice of the word undoubtedly, meaning unquestionably, undeniably, without a doubt, is a robust statement. Yet it is based on limited evidence by Beggs and Murphy, who are commonly cited (Lyons, 2006; Mant *et al.*, 2007; Tymms *et al.*, 2008; Glauert 2009; Archer *et al.*, 2010; Moffett, 2011; McKinnon and Lamberts, 2013). However, the report was in fact drawn from data collected as part of the Wellcome Trust primary study 'Horizons: Starting out in science':

> This scoping study was designed to investigate the main challenges and opportunities for primary science education across the four nations of the United Kingdom. The aim was to provide an overview rather than a detailed picture of the exact proportions of particular views held by members of the science education community. (Murphy, Beggs, Russell and Melton, 2005, p.9)

The Murphy *et al.* (2005) study contains some methodological discrepancies, including that the choice of questions and the relevance of these questions restricted the outcomes of the report. Within the appendices was the suggestion that the researchers should find out 'what actually happens in classrooms' rather than make assumptions based on the data collected so far'' (Beggs and Murphy 2005, p.121). Yet this report is used consistently to support 'the dominant narrative of lack of confidence of primary teachers and the supposed link to pupils' poor attitudes. The issue of lack of resources for teaching science was a key finding in the report as was the difference in responses between teachers of different ages. The findings were obtained by using a 5-point scale, with science being identified by 80% of teachers questioned as their third most confident area. The Wellcome Trust Review (Harlen, 2008) debated whether the ranking of subjects by teachers was a reliable way to assess teachers' feelings of competence in science, as these rankings might instead be influenced by the teachers' feeling of competence in the other subjects. It should be said that this point was raised concerning changes of subject ranking over time, and not purely on the ranking of individual subjects. English had previously been rated as the highest subject in the early years of the National Curriculum (Wragg *et al.*, 1989, Bennett *et al.*, 1992; Sharp *et al.*, 2009). Yet 95% of teachers (Murphy et al. 2005) ranked mathematics as an area of confidence. However, the number of teachers who expressed limited confidence for the teaching of mathematics was 9%, thus providing a statistically inaccurate set of results (104%), or a printing error.

The teachers who responded to this survey were required to teach five lessons of mathematics and five hours of English each week and had received training as part of the government National Strategy initiatives (1998-2004). The Strategy's emphasis on literacy and numeracy was identified as problematic for primary science, with de Boo and Randall (2001) suggesting that the Strategies were a cause of science being marginalized and Tymms, Bolden and Merrell (2008) proposing that science was still a core subject but was taught less often. Other researchers before this time had also questioned the status of science, with Russell, Qualter, and McGuin (1995) reporting that although science was on paper a 'core' curriculum subject, it did not have equal status with the other core subjects.

A connection is asserted between poor teacher knowledge and lack of confidence, when the position on confidence is unproven and some evidence questioning if teacher's subject knowledge is the key factor in effective primary science teaching. Yet the dominant narrative about subject knowledge influencing teachers' confidence is a powerful one, yet there is research that suggests there is no great difference in outcomes for the pupils taught by specialists, because although the specialists had better subject knowledge, the generalist teachers displayed greater positive attitudes, balancing out the inferior preparation and less satisfactory styles of science teaching (Zuzovsky, Tamir and Chen, 1989). However, as the dominant narrative of inadequate primary science teaching might influence future teachers and teaching of primary science, I thought an examination of this historical picture of teacher confidence in science was needed.

2.6.1 Historical measure of confidence in primary science

Primary science teachers' confidence or competence to teach science has a history as far back as the introduction of the primary science National Curriculum (DES/WO, 1989) with Wragg, Bennett, and Carré (1989) first examining the issues using a survey with 901 teachers. [Table 1 records the changes in competence to teach science]. Initially English was the subject most teachers felt competent to teach, with 81% reporting competence compared to 68% feeling competent to teach mathematics, with only 34% felt competent to teach science. This study was followed by a sample of 433 teachers (Bennett *et al.*, 1992), of whom 43% had been involved in the first study. Ratings in primary science had improved, with 41% of teachers reporting that they now felt competent to teach the subject.

There are methodological issues in comparing scores across different research findings as longitudinal studies of attitudes are only reliable when measured using the same people (Reid, 2006), however only 43% of the 433 of Bennett et al (1992) took part in the first study (Wragg et al (1989).

RESEARCHERS	DATE OF PUBLICATION	NUMBER OF TEACHERS	COMPETENCE TO TEACH		
			English	Maths	Science
Wragg, Bennett, and Carré	1989	901	81%	68%	34%
Bennett et al	1992	433	68%	62%	41%
Beggs and Murphy	2005	300	95%	88%	80%
Sharp et al	2009	303	71.9%	70.6%	60.7%
Leonardi et al	2017	902 (SL) 1010 (TS)	N/A	N/A	96% 79%

Table 1. Research on teacher competence/confidence 1989- 2017

There are also issues with the wording of the questions, with Harlen and Holroyd (1997) examining teacher confidence because they believed that teacher competence was too difficult to define, although they found similar results to the Bennett *et al.* (1992) study (cited by Sharp *et al.*, 2009). The national survey (Sharp *et al.*, 2009) sought to compare its outcomes with the results of the Wragg *et al.* (1989) study a decade later. The Sharp *et al.* (2009) study was based on 303 returned surveys and reported that science was still in third place behind English and mathematics, although the question asked was ‘preparedness to teach’ rather than confidence or competence. However, in this study, 90.8% of primary teachers indicated that they enjoyed teaching science. This study also looked at intrinsic and extrinsic factors and asked teachers to rate other teachers. The judgements were made by amalgamation of multiple items, which, as previously discussed, is problematic (See section 2.3.2).

If the Beggs and Murphy (2005) results are viewed within a historical timeline, then at the start of the national curriculum (DES/WO, 1989) about a third (34%) of teachers felt competent to teach science. Two years later this was reported as approximately two fifths (41%). By the time of the Beggs and Murphy (2005) study, four fifths (80%) of teachers were feeling confident (or competent) to teach the subject. The data provided by the Sharp *et al.* (2009) study shows a decrease but the latest survey by the Wellcome Trust finds that 79% or teachers and 96% of Science leaders agreed with the statement 'feel confident to teach science'. The position suggested by this data is very different from that suggested by the dominant narrative indicating that teacher confidence is low', added to which there were some interesting contextual features within the Sharp *et al.* (2009) study.

2.6.2. The contextual features

All studies asked questions about competence, confidence or preparedness to teach and required respondents to rank subjects, although the number of subjects varied. The later surveys contained other questions focused on extrinsic features, such as time and resources, or questions concerning attitudes within the sciences – enjoying teaching biology rather than physics. Sharp *et al*. (2009) reported that those trained after 1998 were better prepared for teaching but only in some areas, which did not include the physical sciences, a finding supported by Beggs and Murphy (2005). The date of 1998 is important as this was when the 'landmark introduction of a national teacher training curriculum for primary science (DfEE, 1998)' happened (Sharp *et al.,* 2009, p.251) and a curriculum of subject knowledge was introduced for education primary science courses.

Another feature reported was that teachers trained before 1998 were less worried by resource adequacy and lack of professional support (Sharp *et al.*, 2009). Perhaps these were teachers who taught before the national curriculum and were used to making do with what was available, mirroring what was found in the Primary Horizons report, or that Guerriero (2017) assertion of the importance of that Procedural Concept knowledge is correct. In-service training was found to be an important feature, but less than 40% of the teachers in the Sharp *et al.* (2009) survey were found to have attended any science training in the last three years. Of the training that was attended, 28% had focused on scientific enquiry with less than 7% of the teachers having attended any subject knowledge training, even though this was a perceived area of concern.

This national data was not representative of a smaller study in Leeds at roughly the same time, where teachers rated their confidence to teach art above science (Llyod, Braund, Crebbin and Phipps, 2000). It should be noted that this project included two teachers from each school and only one was a science leader, and that art was placed in sixth position after English, maths, geography, history, and P.E. (2000, p.357). The scale for judging confidence included terms such as 'fully confident' (10%), 'confident' (63%), 'can manage' (20%) and 'need help' (7%). This research paper has been cited only 18 times (29.07.17), perhaps because 'the rating of these teachers at the end of the course demonstrated that their confidence ratings had, on average, dropped' (2000, p.262). However, again the methodology and scaling scores across different subjects and aspects of science might require justification (Reid, 2006).

The Murphy *et al.* (2005) data was utilised in a study that found that 'most teachers (86%) were highly confident about questioning in science and three-quarters were highly confident in some of the practical aspects of science teaching' (Murphy *et al.*, 2007, p.422). Murphy *et al.* did acknowledge that not everyone thought primary science was poor, and quoted an HMI Inspector stating, 'the one positive achievement of the National Curriculum was a significant improvement in primary science' (Mike Thomlinson, quoted by Murphy *et al.*, 2007, p.418). The discrepancy in some aspects of the results, and the emphasis on science when less than 50% of teachers expressed confidence in Information Communication Technology (ICT), is concerning. There is also evidence of disregarding data that did not fit: for example, the teachers who expressed a confidence in science (Beggs and Murphy, 2005); or minimising the 44% of teachers who did not have a science background but whose science was sound (Harlen and Holroyd, 1997). In the research teachers also identified other issues such as time and lack of resources but it was the confidence issues which were highlighted in the main findings of these reports and used to support the dominant narrative when this report is subsequently cited (Lyons 2006; Mant *et al.*, 2007; Tymms *et al.*, 2008; Harlen and Qualter, 2009; Glauert, 2009; Archer *et al.*, 2010; Moffett, 2011; McKinnon and Lamberts, 2013) Is this an example of Bruner's (2012) conventionalising effect where researchers focus on findings they were expecting, with their belief systems based within the dominant narrative. It also supports the suggestion that peer review might lead to simplification (section 4.3.6). It could lead to questions being raised about the possible mismatch between the perceived need for science subject knowledge for teachers and pupils.

2.7 Tacit knowledge: The 'what' of primary science

Whilst the issue concerning teacher confidence is a key driver for science teaching, the attitudinal issues have been linked to opportunities for pupils to explore (The Royal Society, 2010). If teachers do not understand scientific subject knowledge it is suggested that they find coping strategies such as didactic 'chalk and talk' and rote learning methods (Harlen and Holroyd 1997; Appleton and Kindt, 1999). Yet science subject knowledge, whilst important for teachers, is not often identified as being as important for pupils. However, it is important for future scientists, and the real value of subject knowledge is that it stops scientists from having to start from the first principles every time. There is a basis or an agreed body of knowledge of science at any one time in history, and this is termed by many as tacit knowledge (Popper, 1959; Kuhn, 1962; Feyerabend, 1975). This tacit knowledge is accepted and does not need further clarification or proof. Lakatos (1970) also identifies with this idea but he brands this type of knowledge as 'hard core'.

In education the debate about what is tacit or ‘hard core’ for the primary science curriculum (DES/WO, 1989; DES/WO 1991; DfE/WO, 1995; DfEE/QCA, 1999) is a challenging and ongoing discussion. The discussion of what primary pupils should be taught began in earnest with the design of the first Science National Curriculum (DES/WO, 1989), and was discussed in detail by Black (1995), one of the original contributors. Yet the research debates generally focused on scientific enquiry approaches and attitudes to science rather than whether the subject knowledge was suited to purpose, or even what the purpose of primary education might be. In the case studies that follow, this interest in science subject knowledge is a controversial point. Lakatos (1970) identified degenerative and progressive theories, terming research that was focused on maintaining the ‘hard core’ without adding any new or novel approaches as degenerative, unlike scientific theories that have novel facts confirmed, which he termed progressive. Degenerative theories can be questioned when new information is presented, but they may not change just because evidence is provided. I question if the current understanding of primary science teaching relies too heavily on degenerative theory, the research discussed so far is in the public domain but has not influenced the dominant narratives.

This theory of ‘teacher incompetence’ is fundamental to the research literature and is commonly used to explain the problem with primary science education. In a truly deterministic way, the changes to education in recent years have focused on the issues of teacher understanding, confidence and attitudes, and proposing that there is a causal link between them. I suggest that in primary science the normal theory (Kuhn, 1962) is one of teacher deficit, a theme so accepted it is littered in research focused on other issues – for example, in a paper about the positioning of astronomy in the primary science curriculum, Sharp and Grace (2004) concluded that not only did teachers lack curricular expertise, but this is explained using aspects of the dominant narrative as shown below:

> [P]rimary teachers’ general lack of curricular expertise in science was hardly surprising given that, until then, most had received little formal education in science beyond that taught during their own days at school, and most had received little formal training in science either before or after entering the profession. (Sharp and Grace, 2004, p.313)

This study was arguing against the formulation of curricula by central government dogma, requesting instead a curriculum led by teachers. The lack of curriculum expertise which was first identified by a national primary review (HMI, 1979) and reinforced in 1989, where ‘the ability of teachers to select and utilise subject material matched to the interest and abilities of the pupils they teach’ (HMI 1989, p.6) was criticised. These HMI reports were based on direct observation of a small number of teachers. Subsequently training opportunities were provided and between 1984 and

1987 more than 1,350 science coordinators attended a 35-day paid course, paid for centrally (HMSO, 1989). These funded courses existed into the 1990s in many authorities, and I even continued to run ten- and twenty-day science courses when I began working in a small Authority in the South of England in 1996. Training, both in-school and pre-service, was identified as influencing teachers' views (Murphy et al., 2005; Sharp et al., 2009) but appears to have had limited impact on the degenerative theory of teacher confidence. Others who work with teachers suggest that teaching science might instead involve courage (Byrne, Rietdijk and Cheek, 2016) or the provision of ideas that work (Appleton, 2003) or worked examples (Harlen and Holroyd, 2007) all ideas that are echoed in the biographical chapters.

2.8 Summary

This chapter began with the conception of narratives as how the brain makes sense of information as an evolutionary adaptation which has suited human development and this argument will be developed further in Chapter 4. Attention was then focused on the first research question:

- To what extent is the paradigm for primary science accurate, that states poor teacher subject knowledge and confidence leads to poor pupil perceptions of science, and how is primary science understood in the literature and reports?

We tell stories to make sense of the world, but these narratives are not necessarily based on evidence. I have provided some evidence that the paradigm that primary science teacher's lack confidence may not be reliable for several reasons:

i) Beliefs are not direct entities and there are pragmatic and epistemic reasons for holding specific beliefs. The more often a belief is asserted, on the bounds of probability, the more it turns it into a justified belief. The dominant narrative linking lack of scientific understanding leading to lack of confidence is an example of such a justified belief, and the problem with such a belief is that it influences future actions (See section 2.3.1 and 2.3.2);

ii) The teacher development programme is worth a considerable amount of money providing context related acceptance of the beliefs. (see section 2.33);

iii) It was asserted that limited teacher understanding of science results in the leaky pipeline and evidence was presented that questioned the reliability of this argument (Salzman, Kuehn and Lindsay, 2013) (See section 2.3.4);

iv) The construction of attitudinal surveys influences the reliability and validity of the results (Reid, 2006) and these surveys underpin the dominant narrative of primary science. It is difficult to test attitudes accurately (section 2.4.2);

v) Although scientific enquiry is believed to be an important influence upon pupil attitudes, there are several different definitions and meanings assigned to the term scientific enquiry (section 2.5) and as a result there are too many uncertainties;

vi) The belief of a connection between an exploratory attitude and learning is not assured (section 2.5.1);

vii) Children's attitudes are thought to be crucial to the 'pipeline' but children's attitudes to primary science have remained constant despite enormous changes in teaching (section 2.5.2);

viii) A connection is asserted between poor teacher understanding of science and lack of confidence, when the position on confidence is unproven and some evidence suggests teacher knowledge is not a key factor in effective primary science teaching (section 2.6);

ix) There is strong evidence that teacher confidence has improved considerably since the beginning of the National Curriculum (see section 2.6.1);

x) There are dangers in defining a limited set of required teacher knowledge about science, and particularly the linked assumption that this is providing the key to effective teaching (see section 2.6).

This literature will continue to inform the analysis of each successful science educator's story. Science education was mentioned by several the participants as being the same as science and some even referred to themselves as scientists, so an examination of the differences between the sciences and science education, is the next stage, to examine the worldview of science.

Chapter 3: The sciences and science education

3.0 Introduction

This chapter tries to identify why some dichotomies exist in our understanding of science and science education which manifest themselves in the thinking of the research participants. This chapter does not end with an answer rather it tries t to understand both the perspectives of the participants and my own. Considering the character of the sciences and science education led to 'antinomies', defined as pairs of contradicting laws (Bruner 1996, p.66). After examining the history of science and determining the meanings of the sciences and science education, consideration is then given to the current challenges regarding primary science education.

I acknowledge at the start that my view is just that – one of many possibilities, and there is not just one version of the sciences or of science education, as interpretations do not exist independently of people. Heidegger's view of 'Being' is contrasted with Rorty's (1979) pragmatic framework, although neither approach is found to be unassailable. It is also worth stating that whilst I now accept that there is not one method of science, this is not the same as suggesting there is no method at all (Feyerabend, 1975).

3.1 My changing perspective

In this chapter the complexities are examined from the viewpoints of scientists, philosophers of science and science education authors. However, I note that one of the complications in contrasting the sciences and science education is that much that is written about the sciences comes from philosophers of science and science educators who were never scientists; for example, Popper was a psychologist and qualified elementary teacher, and Francis Bacon was a lawyer and barrister. Where possible the views of scientists are used to define the sciences, although it must be noted that, generally, scientists write about a small branch of learning within their own area of study, rather than the umbrella term science (the sciences).

In the past, I have taken science education to be synonymous with science, something that is in common with the stories told by some of the successful science educators (see Chapters 6, 7 and 8). As a result, questioning the complexity of this area has made me confront previously held beliefs. Bruner has something to say on questions that challenge: 'when things are as they should be there is no need to question what is, when there is an exception, there will be a story to tell the reason' (Bruner, 1990, p.49). So, a story is now required to illuminate the differences between the sciences and science education, and whilst I could begin with science education, I have selected the sciences as the starting point as the participants narrated differing views of science.

3.2 The concept of the sciences and the scientist

The sciences have not always enjoyed the cultural and institutional security they now hold (Yeo, 1993). The concept of a scientist is a recent phenomenon, created by Whewell in 1833, who himself played a key role in shaping the science, learning and culture of his time (Weber, 1999, cited by Jenkins, 2007). There is a debate about whether Whewell was a scientist, as he was a historian and philosopher, but as he was awarded a medal by the Royal Society in 1837 for his work on Tides, he would count as a scientist by the very definition he was generating. Jenkins (2007) suggests that he created the term scientist along with setting up the British Association for the Advancement of Science (BAAS) in the 1840s for political reasons. The sciences at this time were expanding and many new scientific disciplines were being formed. Jenkins offers a plausible theory that Whewell was concerned that if all the new disciplines of the sciences were not merged, 'science' overall would be politically less powerful. As a result, the sciences would not be able to lobby successfully for money and would be unlikely to play a key part in the future of education and culture. Whewell himself was elected to 15 learned societies as wide ranging as the Royal Astronomical Society (1821) and the Institute of Civil Engineers (1837), not an insignificant feat for a historian. His membership of these groups would have helped to consolidate his influence alongside his network of influential friends such as Darwin, Lyell, Herschel, Huxley and Babbage. Retrospectively, his aim to prevent the many new disciplines of the sciences breaking away and becoming separate entities, making 'science' less influential, appears to have been achieved.

However, it was more likely to have been a larger group rather than Whewell alone that enabled this to happen. This view would be supported by the changing understanding of public science, which resulted in the increase in scientific publications for the general public. Barton (1998) identifies that the number of science journals doubled between 1850 and 1860, and whilst this increase in part could be owing to the reduced cost of printing, resulting in a greater number of publications of all types, the type of science publications also changed. The changes in both form and content reflected the changes in the scientific community. The 'growing independence of science as an institution and its growing significance to the broader society' (Barton, 1998, p.4) was represented in these articles and journals. As the great man said, 'Science is no longer locked up in convents or colleges under the monopoly of the privileged classes, but has stepped aboard visiting her disciples in cities, fields and camps…' (Whewell, 1847, p 4). Whewell's presupposition was science would provide social change and its findings would be used by farmers and the army. Throughout his work Whewell discussed Science, although, when discussing ancient time, he used the term the sciences identifying that it was important to learn from scientific history (Matthews, 2012).

Another device Whewell used to signify change was to alter 'Men of Science' or 'Natural Philosophers' into the new term 'scientists' (Yeo, 19893), and although this name did not catch on immediately, it was a successful unifying device. Whewell succeeded in uniting the sciences and therefore in this chapter the term science will denote the success of his actions.

3.2.1 What is the 'being' of science'?

The term scientist is now accepted and used to define those who work in many diverse disciplines. It is also used by those outside science to describe these very varied activities as having one set of practices. The 'being' of science is a way of looking past what is currently known and to question why the world is divided up in the way it is. The Heidegger (1962) study of 'being' is one way to provide an explanation of the struggle for a definition of science and provides and explanation for the diversities of the views of science held by the successful science educators whose stories are told in chapters 6-9. Heidegger (1962) postulated that, philosophically, science exists whether people believe in it or not. Science shares its views and practices, and as a result it already is. Heidegger focused on the human *dasein*, and how 'being' links the network of things in a person's world directly to its needs and purposes. Heidegger identifies, as a central idea in *Being and Time* (1962, p.175), that a person's *dasein* is affected by what others think, say and do. The influence of these other people, who can be described as 'they', occurs by tradition, culture and doctrines. I have had a need for a unified notion of science in my role as a science educator and note that the others that influenced my own notion of science were ATs, tutors and a network of colleagues (Chapter 1). Those who shared their stories in this work show this is a common influence, with many of the science educators also becoming part of the 'they'.

Heidegger's analogy of a building in '*About Metaphysics'* (Heidegger, 1927/2000) helps to begin to unpick both science and the idea of there being a 'they'. The use of the analogy of a building is helpful in representing how different perspectives on the same things can exist. My previous building of science was a citadel, where scientific realism was secure. Science like Heidegger's building can be looked at from many angles, from all aspects or components. My supervisor might view science as a prison that prevents other domains their place and encourages a blind fanaticism for epistemic 'truth'. There are many buildings of science, and the interpretation of science will differ if the examination is from the perspective of one of the pure science subjects like physics, compared to a 'softer' science like psychology. I struggled to accept that scientific facts were not absolute. I had been encultured into the science view (Aikenhead, 1996) and scientific thinking dominated my everyday thinking, resulting in the idea of 'being' challenging my *doxa* (Bourdieu, 1990). To my question 'is there a "being of science"?' Heidegger's answer would be yes, as he maintained that a window or a tree exists as a 'being' (Heidegger, 1927/2000). Heidegger's preoccupation with 'being' raised several questions about what science could be. By undertaking the research for this thesis, it became clear that the concept of science, like Heidegger's 'building', was not seen identically by all, so scientists, educators, students and the 'public' can have a different view of science. To take the Heidegger analogy further, those that sit in the 'building of science' see it from the inside, and from there it is 'what it is' and 'how it is'. They can smell the 'being' of science; they are engaged in their private view of science. Heidegger advocates in the case of his building that the smell remains many decades later, and this smell in the nose provides 'being' much more directly than any description might (Heidegger, 1927/2000). Only one participant had ever stepped into a 'building of science' and as a result the participants' presuppositions had been formed within the 'buildings of science education'.

Previously, when primary science at university was taught in science labs, shared with university Life Science departments, students would often comment upon the smell and how it reminded them of school science. For some this was not a positive experience, which is a reminder that those who have sat in a 'building of science education' will have their own interpretation of science and science education, and as a result there are many public views. It is also a reminder of how memories and past experiences go on to influence future practice (Lortie, 1975; Roberts, 1982). Additionally, those who study one branch of the sciences will be involved in different practices to scientists from other branches; their buildings differ. So, one could argue that Whewell and his associates' aim to promote a view of unified science to the outside world of 'they' was successful from an educational standpoint, yet in the inner world of science there still exist many differences. These ideas will be developed further in Chapter 4.

3.2.2 The sciences before Whewell

The sciences have a history longer than the version created by the BAAS. Science is often said to have started with the Greeks, although Olson (1983) presents a clear case for it being found in the near east, in Babylon and Mesopotamia far earlier than the time of the Greek philosophers. Even from its inception to tax farmers and plan agriculture, science was not a fixed discipline but one that evolved and changed throughout time (Olson, 1983). Wolpert (2000) would argue that planning agriculture is technology, not science, and that a lack of discrimination between the two domains has ‘played a major role in obscuring the nature of science’ (p. 25). Hurd (1997, p. 414) would suggest that as science is changing and growing there is a ‘symbiotic relationship between science and technology’. Wolpert was a scientist and Hurd a science teacher so this might explain the differences. Whilst the sciences are now composed of many disciplines, the earliest interpretation of science was composed mainly of astrology, a discipline that became unpopular and decidedly unscientific by the time of the scientific revolution. Public science tells of its origins in physics and logic, the subjects that were at the heart of ancient Greek science. In fact, the study of the natural philosophy and ‘Phusis’, the fundamental Greek word for nature, are more likely to have been the starting point for modern science (Olson, 1983). The reality, as in much of public science, is rather more complicated, but science seen as the study of Nature is another dominant narrative. A view held by some even today – ‘an overarching epistemological goal of science is to develop a comprehensive, systematic, empirically grounded understanding of nature’ (Elgin, 2011, p.251).

Although ‘scientist’ was a new word, the term science was not, originating from the Latin ‘scientia’, which is defined as knowledge – a knowing or expertness. Historians of ancient science studied the ‘sciences, which was the systematic knowledge of nature’ (Aikenhead, 2006, p.7). In the fourteenth century, science in England was defined more as ‘book -learning’ and only became experimental in nature during the Scientific Revolution. Francis Bacon was instrumental in devising a new way of working, based on induction. Bacon was interested in artefacts, but his proposed method of practical experimentation is often identified as being when the methods of science came into being. Herschel, one of Whewell’s contemporaries, proposed that whilst there are departments within natural philosophy (today called science), they are united, and all have the ‘one method of enquiry’ (Herschel, 1831, p.219). Herschel could be given the label of an amateur scientist, and he was one of the last gentleman scientists working on scientific activities because he had the means to do so.

The change from amateurs to professional scientists coincided with Whewell’s aim to improve the public understanding of science firstly by the publication of the *History of the Inductive Sciences* (1837), followed by the *Philosophy of the inductive sciences* (1847). The replacement of the ‘men of science’ and Whewell’s rhetorical pleas for science being released from convents, aimed to persuade state and civic authorities to fund scientific institutions and research, which was crucial for the development of a professional science. Whewell was passionate about what science could achieve as the following demonstrates:

> “when the knowledge of nature shall be rightly pursued, it will lead to discoveries that will as far excel the pretended powers of magic, as the real exploits of Caesar and Alexander exceeded the fabulous adventures of Arthur of Britain or Amadis of Gaul.”
>
> (Whewell, 1847, p. 12)

Whewell had a passion for science and created a public image of science in order to question 'a certain caste in society' (1847, p.4) detached from religion and better than magic, and, once a boundary was created around science (Barton, 1998), I believe it had a lasting impact on public perception of science and science education. The biographies in chapter 6-9 also demonstrate this passion for science.

Although the origin of the term nature was 'of emerging', derived from the Latin word *natura* - to be born – today science is more commonly viewed as 'the motion of material things, of atoms and electrons, these are the modern things that physics investigates' (Fried and Polt, 2014, p.17). Hurd suggests the traditional subject entities now have no relevance as there are over 400 named fields of biology requiring more than 20,000 journals to report findings (1997, p. 409). Although, as the objects that science study becomes more abstract, for example, quarks, the debate should be whether science is the study of what nature reveals or the creation of models by human minds (Rosenberg, 2005).

Whilst science has never been so successful or had a greater impact upon daily life, the ideas of science are still alien to many (Wolpert, 2000). Science, whether public science identified by those outside science, or the private science of the scientists, is clearly not one thing and it has changed over time (Kuhn, 1962). Kuhn suggested that science is not cumulative but goes through revolutions. This is a disputed point; with Lakatos (1970) instead arguing that whilst scientific ideas change this was because new ideas were needed. Yet that change could not occur if there was not another theory ready to take the place of the previous ones. However, the idea of scientific revolutions and the incommensurability of science was instrumental in changing the public perception of the objectivity of science. Kuhn's approach, which took an historical approach to the 'advances' in science and questioned how scientific understanding was created, restarted debates about the nature of science. Alongside these debates came greater attacks on the objectivity of science, something which Kuhn had apparently not intended (Kuhn, 1977). However, it is worth stating that because Kuhn looked at public science from a historical perspective, he classified it as one entity; he too was discussing the public face of the sciences and not what was happening in current scientific research. Hacking (1983, p.10) recognised that Kuhn's scientists were not the multinational groups that characterise today's sciences but instead were small groups or individual researchers. This, as will be discussed later in chapter 4, influences the story of science, told by Kuhn (1962). The methods of the sciences can be perceived as another dichotomy.

3.3 The methods of the sciences

It is not just philosophers and teachers who hold a simplistic view of the sciences. C. Jackson (1930), in his presidential address to the Minnesota Chapter of The Society of Sigma X1 (the scientific research society), said that the epistemological aim of science is to understand nature, even though nature is extremely complicated and scientific findings are fallible. Jackson, a scientist, argued that over time humans had noticed that there appeared to be order and regularity in events. He also acknowledged that whilst all the sciences were different, all branches had some core beliefs (Jackson, 1930, p.79).

Jackson's views about science are aligned to Dewey's (1903) interpretation of science as a method of thinking. Jackson quoted Leonardo da Vinci: 'No human investigation can call itself true science unless it comes through mathematical demonstration' (Jackson, 1930, p.80). Jackson's classification would include the abstract mathematics of Galileo or Einstein, but it would also exclude most of the science taught in primary schools, where it is observation and induction and not mathematical demonstration that prevails. Yet Jackson identifies an important point - everyday life does not demonstrate mathematical science and as a result a more helpful definition is that such scientific thinking is often unnatural and is not like common sense and cannot be 'acquired by simple inspection of the phenomena' (Wolpert, 2000. p.1).

The experimental method formalised in the seventeenth century, is now firmly associated with the public view of science and science education. The advantage of this method, which is discussed by all participants in this study, is that it enables experimenting, testing and trying out ideas. It provides the opportunity to 'take nature on' (Jackson, 1930, p.81) without waiting for something to be observed, because passive observation or uncontrolled tests do not provide answers, they only raise questions. With a 'one method' stance, it might be assumed that science provides fixed universal laws, and yet this is not the realm of many branches of the sciences. However, this idea of universal validity is not explicitly questioned by many in western society, and the intellectual certainty of the sciences is taken for granted, with few appreciating how modern culture has been assimilated and moulded by such a view of science (Olson, 1983). Scientists know that laws are not fixed and can change, that evidence is never complete (Schizas, Psillos, and Stamou, 2016). Although Schizas *et al*, question the 'family resemblance' idea of science, proposing instead that science comprises of heterogeneous practices and each discipline has its own unique features (2016, p. 709). In order to understand the methods of the sciences further it is necessary to look at what scientists say they do, their private methods of science.

3.3.1 Private science methods

Contemporary practices in the sciences recognize that both the conceptual frameworks and the methodological practices have altered and that these modifications are a consequence of new tools, new technologies, and new explanatory models and theories. These in turn have shaped and will continue to shape scientific understanding and scientific practices. Science educators talk about a 'method of science' – scientists such as Conant (1947) preferred instead to talk about the 'tactics and strategies'. The methods are not any single kind of logical and social exercise but, rather, diverse and multidimensional and necessarily so, given the wide range of phenomena that the sciences continually seek to understand, explain, and experience (Galison and Stump, 1996; Cartwright, 1999; Longino, 2002). Wolpert also recognises that there is no one method that provides the blueprint for discoveries and instead suggests 'do what makes your heart leap; think big; dare to explore where there is no light; challenge expectations; be sloppy so something unexpected happens but not so sloppy so you can't tell what's happened… there is no such thing as the scientific method' (2000, p. 108).

The expectation of a 'one method' approach was demonstrated by Latour and Woolgar (1979) in a book entitled *Laboratory Life*. This ethnographic study of scientists was conducted at the prestigious, Nobel Prize winning Salk Institute, set up in the 1960s by the scientist who developed the polio vaccine. *Laboratory Life* provided a very different picture to the public view of the scientific method and led to questions about whether what happened in this laboratory was reliable or objective. Latour and Woolgar's conclusions were that the scientific method was a 'fairy tale' and the scientists often made judgements about what data to keep, what to ignore and that science was far more subjective than the public perception of objective science.

Jonas Salk, the head scientist of the facility (1979, pp.11-14), wrote an introduction to *Laboratory Life* in which he identified that although the methods used by Latour were honest, they did not tell the whole story. In part this was because Latour and Woolgar were laymen, so they identified only the things which were easiest to understand and that these were the superficial aspects of laboratory research. Salk went on to suggest that *Laboratory Life* should be considered an achievement. Osborne (1986) argued that this study did not make science relativist because the research matter, the determination of the molecular structure of TRF hormone, was new, and the methods of creation in the sciences are very different from the methods of verification. Einstein (1934) had already acknowledged that there were two types of science, one 'existing and complete' and the other 'science in the making'. 'Science as something existing and complete is the most objective thing known to man' (Einstein, 1934, p.112). Yet, 'science in the making' is subjective and as irrational as any other type of human activity. These opinions could be interpreted as science being subjective, although Wolpert (2000) has argued that in fact it is the skill of the scientist to know what to interpret as vital and what to ignore. Later in this research, one of the participants, Peter, demonstrates how this works [Chapter 9.] His ‘aha’ moment might be the skill of the scientist or perhaps considered by some as part of science, the ‘fairy tale’. Rather than suggest *Laboratory Life* was problematic for science and scientific research, Salk (1979, pp.11-14), proposed that all science facilities should have sociologists working with them so together they could help the public have a better understanding of the sciences.

However, ‘science in the making’, this complex, skills-based intuitive approach, is not found within the building of science education, which deals with facts that exist and is complete. ‘Science in the making’ is more about shared understanding, values and practice, which are even more important as the sciences are now conducted by big teams.

3.3.2 The big teams of scientists

In the past scientific discoveries were made by a small number of scientists often funded by rich patrons. Today it is immense groups of scientists funded by multinational companies or governments (Elgin, 2011) who tackle a host of new problems, such as clean renewable energy sources, greater yielding crops or the eradication of genetic diseases. Science now requires a great deal of collaboration and such collaboration requires trust and a division of cognitive labour (Elgin, 2011). The paper that reported the sequencing of the human genome had no fewer than 250 authors working across four continents, all contributing (Venter *et al.* 2001, quoted by Elgin, 2011, p.252). Hurd (1997, p. 410) acknowledged the pace of change ‘Today, 95% of research reports are multi-authored; at the beginning of this century the number was 5%.’

Elgin reasoned that for these large teams to work collaboratively they must share common understanding, values and practice. The members of these collective teams of scientists each bring different skills, but for this to be successful, scientists must build upon each other’s findings, or question them. Few scientists now work alone, and they will use machinery calibrated by others as well as employing methods devised by unknown predecessors. I spend a day a week in a science research facility where I am linked with teams of scientists who do many different things, from trying to create cancer drugs from spider venom, to making food supplements from algae, without the fish phase. These scientists all use slightly different approaches and there is a vibrancy and urgency to their work. An embedded researcher might question these varied practices, but this is the reality of cutting-edge research: it is trial and error, and the fact that many different methods and approaches are used is not counted as newsworthy within this science community.

Elgin's (2011) argument and my own observations support that there is not a single method, but instead teams who share values and ethics. Rorty (1991) acknowledges that although there is no reason to praise a scientist for being more 'objective', 'logical' or devoted to the 'truth' than others, there is reason to praise the institutions that they have developed and within which they work. Rorty even suggested that these structures would be beneficial for others to adopt, particularly the concept of 'unforced agreement' and 'free and open encounter' (Rorty, 1991, p.39). So, 'private science' appears to be unified by values even if the public view of the sciences is still fixated on science with a single method. I would caution that Rorty is discussing the public face of science, which does not include any 'unscientific behaviour' such as Oppenheimer accusing Bohm of being a 'Trotskyite' and stating, 'We will refute Bohm by not reading him' (Dusek, 2017, p.11). Such an approach would not be demonstrating scientific attitudes or values expected by science education.

One of the unifying structures that the sciences have created is the International Council for Scientific Unions (ICSU), created in 1931, to promote international scientific activity in the different branches of the sciences and their applications for the benefit of humanity. It is part of UNESCO and one of its aims is to break down barriers between the individual sciences. The World Declaration of Science was ratified in 1999 and aimed to provide a new social contract for science, based on four principles: science for knowledge and knowledge for progress; science for peace; science for development; and science in society and science for society. These principles are focused not on methods but on upholding values, ethics and principles of science such as open access for research, cooperation between scientists and governments across the globe, education, and the need to protect both present and future generations.

Modern science has become technical and very different from the science that preceded it, and therefore both scientists and non-scientists express alarm at the possible appalling uses of science (Hurd, 1958), such as the atomic bomb and chemical weapons. Some have questioned whether such things could be prohibited in the future, and others questioned if science was really 'the best investment for the future of mankind' (Hurd, 1958, p.15) However, the economic argument is seductive. This is not surprising as it is supposed that science has been led by the needs of humanity - for example, the initial need for a calendar was assumed to be the driving force behind the necessity to understand the solar system. This drive to improve humanity via science is clear in the

World Declaration of Science, which also states that for society to develop further, education in science is important:

> [T]hat access to scientific knowledge for peaceful purposes from a very early age is part of the right to education belonging to all men and women, and that science education is essential for human development, for creating endogenous scientific capacity and for having active and informed citizens' (Unesco, 1999, point 10)

The concept of the endogenous scientific capacity of humanity suggests that science originates within humans and is an individual right as well as a societal need. This need for science for human development could be viewed as enabling humanity developing as a species, (the evolutionary argument which will be developed further in Chapter 4) or as required so that everyone can maximise their potential through individual endeavour. Whilst the case studies later in this thesis focus upon the role of science from the perspectives of successful science educators, for some their work is focused at the level of society. This role of the individual and society is only one of the issues that science education must contend with.

3.3.3 Summary

The methods of the sciences have formed a significant segment of this chapter, as practical science is discussed most in the case studies that follow. This chapter has discussed that:

i) Science and the term scientists were created in the 1830's as a unifying device alongside the development of a public understanding of sciences (Section 3.2);

ii) Heidegger's view of 'being' was used as a method to explain why there can be so many versions of and approaches to science (section 3.2.1);

iii) Private science is carried out in laboratories all over the world, something called 'science in the making' (Einstein, 1934), which differs from finished science. What happens in these laboratories depends on the view of epistemology that the observer brings to their work and understanding how any specialist system operates takes time. Public science is the finished product (section 3.3);

iv) The agreed practices of the sciences might seem a mirage, but large teams do work together to support life on the planet (Elgin, 2011).

The sciences are no different from entering any specialist world or domain (see Chapter 4) and scientists demonstrate human frailties. Next, science education is put under the spotlight to examine further the buildings (Heidegger, 1962) created by the participants. This section has focused on the first research question and how is primary science understood in the literature and reports, but because of the nature of the research methodology all questions are linked throughout. The participants did not see science and science education as different; some of these issues will be discussed again later in the biographical chapters.

3.4. Science education

As I started to work alongside successful science educators, some elements of their stories mirrored my own. I realised that I too used science and science education interchangeably treating them as a single domain. Yet other key aspects of their views differed including their definitions of science education itself. As I began to interrogate the science understanding - confidence narrative, I found I needed to examine the literature on science education in order to understand more fully the life stories. This section identifies some of the literature that helped my understanding of the biographies that follow.

One definition of science education is the process of teaching and learning about science concepts and processes (Singer, 1921). Holton (1973) identified science education as 'public science' defined as 'that which students and most non-scientists would identify with, what is taught and what appears in text books' (Holton, 1973, p.386). How public science is often interpreted is learners finding out more about their world: science as furthering human understanding of nature. Yet this view of science education 'represents only a narrow slice of the myriad intellectual, social and cultural practice that falls under the rubric of science' (Rudolph, 2014, p.15). 'Science in the making' bears little resemblance to science as the institution - 'our inherited world of clear concepts and disciplined formulations' (Horton, 1973, p.387). The disparity between science and science education seems clear, but this leaves questions for the role of science education.

Nussbaum (1989) perceived the role of science education as to teach knowledge in a rationalist and empirically positivistic way and to describe this knowledge in absolute terms: 'the true, proven, confirmed, right and correct knowledge' (Nussbaum, 1989, p.530). However, not all science educators hold this approach to be beneficial or would agree that there is only one 'correct' science. One such person was Joan Solomon. Her work on the public understanding of science was instrumental in questioning the role of science education for most learners who would not become scientists. Solomon eloquently describes the idea of one true science as being like the search for the unitary edifice of correct science, 'found like gold at the bottom of the crucible under a crust of crude misconceptions which were hiding it from the world' (2013, p. XII).

Solomon's (2013) final research project was undertaken in a market town, where she identified that whilst science once was rare, easy to identify and conducted by the few, it is now part of everyday life, impacting on all people and conducted by the many. Her work identified that public science is not a simple thing and that humans can hold both a scientific view of nature and a different personal view at the same time. This 'cognitive apartheid' (Cobern, 1996, p.588) is discussed by Peter in chapter 9. Solomon argued that science education that is comprised purely of subject knowledge misrepresented science, a view supported by Stephanie (in chapter 7) but challenged by Ben (in Chapter 6). Solomon's work was also clearly motivated by the role of science for the individual, but she was undoubtedly aware of the role of science in economic terms. Her focus was to create informed citizens, which is a clear aim in all the case studies that follow. The challenge was how science could connect with attitudes and personal beliefs but remain as Science (Solomon, 1994). This is a central issue in the narrative of science and forms a starting point for examining the challenges in science education.

3.5 Challenges in primary science education

One of the challenges for primary science education is the approach taken to epistemology, suggests science reflects reality. This stance influences the type of learning promoted and underpins other challenges in primary science which include: its role; scientific literacy and vision for science, and how science is seen as a single entity. These challenges will be discussed in turn as they feature in the biographies and contribute to the paradigm or dominant narrative of primary science, where poor subject knowledge and low confidence influences the teaching of science.

3.5.1 The role of Primary science

The 'pipeline', the economic argument for science teaching has been discussed; however, there is a question as to the other roles that are possible for primary science education. Whether primary science is to: provide the next generation of scientists (HMI, 1989; HM Treasury, 2006; Royal Society, 2010; DeWitt *et al.*, 2013; CBI, 2015); provide personal understanding and satisfaction for the learner (Cobern, 1996; Solomon, 2013); or to develop the learner's cultural capital (Archer, *et al.*, 2015)? The 'pipeline' argument seems to focus directly on the needs of society rather than the individual, although there is a continuum between society and the individual (Eisner and Vallance, 1974, cited in Pollard and Tann, 1993). At one end of this continuum is the role of science education to enable the individual to fit into society as it currently is. Youngsters in the Wellcome Trust (2011) '*Exploring young people's views on science education'* identified that studying science contributed to their own personal development. At the other end of the continuum, the purpose of science education could be to enable constant improvement and purposeful change of society. Successful science in this arena might be altering society in such a way that there are resulting changes to how the sciences are performed in the future**.** All the research participants were passionate about science with most identifying the role to provide scientists of the future, which perhaps suggests a belief in the certainty of science.

Roberts (1982) advises that 'what science is' depends on the interpretative frame of the teachers, which he found to be bounded both by their own education and teacher training and resulted in an emphasis on completed science instead of the complex multidimensional subject that it is. Whilst debates about public science were happening in the field of philosophy of science, they were not having an impact on the practice of primary science education. Perhaps because teachers are 40 years behind the philosophical debates about science (Elkana, 1970), they are unaware of these views and therefore do not consider these in their teaching (Elkana, 1970; Nesta, 2017). Hodson (1985, p.220) agrees that myths about science and scientists abound because they were adopted by teachers as part of their apprenticeship and they in turn then use these impressions in their future teaching (Lortie, 1975).

If Herschel (1831) was instrumental in creating the scientific method myth, this myth is still prevalent and makes the term scientific method the 'twentieth century version of the universal panacea' (McLaughlin, 1954, p.38). Whilst there is not only one method in science, the practice of science is depicted by most as rational thought (Zimmerman, 2007; Tolmie, Ghazali and Morris, 2016), where the main components include practices such as 'observation, hypothesis, implications and verification' (Mcloughlin, 1954, p.41.) What is taught in primary schools is often a set of procedures or set of rules, something that the Oxford dictionary also defines as an algorithm. Yet this algorithm does not consider the fallibility of observation or how theories inform ideas.

Those who value the 'pipeline' function for primary science sometimes highlight a 'real life' science (CBI, 2015, p.12) emphasis. The CBI suggests that '[l]inking the curriculum and learning at school to real life problems and solutions that primary pupils can grasp would help to support the development of this knowledge and more positive attitudes' (CBI, 2015, p.12*)*. Yet other educators and teachers may favour an individual approach that focuses on the individual's curiosity and happiness:

> 'Learners should be stimulated and promoted to be interested in sciences with their enthusiasm, curiosity, intentionality, and happiness to explore knowledge and to collect and analyze data obtained from their discoveries. These lead to the answer for any question.' (Chantaranima and Yuenyong, 2013, p.2286)

This individual approach values the learner and their entitlement to education and what will make them happy, providing opportunities to explore science from their own perspectives. In the same way that there is no clear definition of successful science the role of primary science is also unresolved. All participants discussed scientific literacy but again in different ways. However, it is acknowledged that in many curricula, more than one emphasis is used, and these approaches are not all mutually exclusive (Roberts, 2007). It appears that the approaches selected by successful science educators are influenced by the types of learning experiences they value and therefore promote to teachers.

3.5.2 Scientific literacy and visions for science.

Today's digital technology provides greater demand for, and access to, scientific facts via media and electronic sources. The composition of effective science provision is debated and there are many suggestions as to what this might entail: the CBI (2015) identifying industry links; the Royal Society favouring practical activity; Nesta (2006) suggesting scientific enquiry; the current National Curriculum's focus on subject knowledge (Oates, 2011); or authentic activities (Friesen and Scott, 2013); perhaps understanding 'the whole game' is beneficial (Perkins, 2009). There is overlap within these approaches but identifying the role of primary science might be as challenging as finding the philosopher's stone. The current 'one size fits all' approach is not effective if the numbers of students who will go on to study science is considered:

> A simple examination of the student population in the United States shows that only about 8% of the general high school population ends up with a STEM degree of one sort or another. But even if it were as high as 10%, it is fair to ask what sort of science education we are providing to the other 90% of our future citizens? (Rudolph, 2014, p.1076)

Whilst this is American data, the issue is common across the western developed world, and if 90% of students leak out of the pipeline, it's not surprising that there is an argument for scientific literacy for the remainder of the pupils (Osborne, 1996), a point that Stephanie takes up in Chapter 7 with her debate about the 'big group'. Goals that are focused on future citizens are thought to be different from science education for procedural expertise and disciplinary knowledge. Roberts originally developed ideas of seven curriculum emphases (1982) which were: everyday coping, the structure of science; scientific skill development; science, technology and decisions; correct explanation; self as explainer; and solid foundations. Later he categorised these emphases into two visions (Roberts, 2007).

Vision I comprises: The structure of science; correct explanation; scientific skill development; and solid foundations, where the focus is within the domain of the sciences is towards the canonical view that science will be required for future study.

Vision II comprises: Everyday coping; science, technology and decisions; and self as explainer, which looks outward towards society and imagines the learners as future citizens who will need to understand and make informed judgements upon scientific endeavours.

As will be identified in the biographical chapters, elements of these emphases are found in participants' accounts with most demonstrating a Vision I approach, while all demonstrate an interest in everyday coping – for pupils to understand and then control their environment and learn science they can apply outside school.

The 'doing' of science is seen as important but there is a dispute about the importance of scientific skills and the position of scientific facts by the participants. Underlying this dichotomy is the basis for a belief system centred on the challenging issue of scientific realism. Feyerabend (1993) would argue that a science education should be one that facilitated choice, not one that guaranteed a predetermined 'truth'. This debate was central to his view of science education and was developed because many of his students were disenfranchised from science. Feyerabend fought against the interpretation of the sciences as objective, unified and value-free: 'the myth of science' which simplified science and prevented alternatives by 'bending minds' (Feyerabend, 1993, p.162). His presupposition was that science should be taught as 'one view among many and not as the one and only road to truth and reality' (Feyerabend, 1993, p viii), something he had in common with the scientist Ziman whose position was that

> once we have cast off the naïve doctrine that all science is necessarily true and that all true knowledge is necessarily scientific … very practically in matters of life and death, our grounds for decision and action may eventually depend on understanding what science has to tell us, and how far it is to be believed. (Ziman, 1978, p.2)

Perhaps this is a statement which could be viewed as relativism, but it can also be regarded as just a different view of 'public science'. If the learner is 'released' from the 'daily flux' of their 'local world'; they can begin an 'initiation' into 'an inheritance of human achievements of understanding and belief' (Oakeshott, 1989, p.59): this Vision II perspective which questions a science-centred worldview is not found in many curriculum documents (Roberts, 2007).

Yet, the question of whether it is the facts of science for their own sake, or if it is the skills of science that should form the basis of the curriculum has been debated since the beginning of the 20th century. A dichotomy exists between those who view primary science education in terms of children being given opportunities to do 'real science' as little scientists, (see Chapter 8) and those whose approach is predicated on science education for the acquisition of canonical science knowledge (See Chapter 6). Layton, Jenkins, Macgill and Davey (1993) argue that the 'knowledge approach' is limited by being a front-end loaded system, tasked with the impossible role of delivering a lifetime's worth of scientific understanding between kindergarten and adolescence. This is a view ardently denied by Oates (2014, p.71) who sees nothing wrong with a curriculum that is prescribed in a carefully sequenced development of key ideas, core knowledge and fundamental operations. Oates was included in working party which decided on the structure of the 2014 English National Curriculum.

Roberts (1982) argued that the content is less important than the curriculum emphasis: that what is said, alongside as what is left unsaid, the 'meta-lesson' (Schwab, 1962) is what counts. The science curriculum has developed a view of 'Science as a 'rhetoric of conclusions'', providing the pupils and their teachers with the meta-lesson 'that the assertions of science are inalterable truths' (Schwab, 1962, p.42). In the English primary curriculum (DfE, 2013) the rhetoric promotes canonical knowledge of science, built as a sequence of key ideas (Oates, 2011). The curriculum emphasis is on 'solid foundations' (Roberts, 1982) and primary science as the foundation for secondary education.

Interpreting primary science as a solid foundation is not new particularly the focus on 'an accumulation of ready-made material with which students are to be made familiar' (Dewey, 1910, p.122). Dewey thought such an approach to science teaching missed the point because there was 'not enough about science as a method of thinking' (ibid). Dewey did not correlate practical science with thinking, advising '[o]ne's mental attitude is not necessarily changed just because he engages in certain physical manipulations' (1910, p.125), a view shared by Peter bin chapter 9. This distinction between scientific thinking and practical work is not commonly deliberated, but this is not unexpected as many teachers focus on the motivational aspects of practical work rather than identifying practical work as the opportunity to learn a concept or a skill (Holman, 2017). The belief that children enjoy practical science is not clear cut with the PISA data (2006) identifying that pupils did not enjoy all kinds of practical work (Kjærnsli and Lie, 2011). The importance of practical work will be returned to in the biographical chapters and in Chapter 10.

Scientists such as Medawar, Feynman, and Einstein all accepted that the sciences are not and never have been objective or value-free and approached the study of the sciences in completely different ways. Feynman explained most aspects of physics in terms of jiggling atoms using diagrams that were as unique as he was. Science teaching requires a culturally based curriculum otherwise students cannot be productive citizens (Hurd, 1997). One critical feature of science is the use of imagination and creativity, the ability to see things in a different way. Erich Jarvis, a working scientist, said that '[s]cience and dance are very similar to me. They both require discipline, creativity, invention, and lots of effort that in the end rewards you with something new' (Erich Jarvis, cited by Bernstein 2015, p.686). Perhaps currently there is too little emphasis on creativity and opportunities for thinking in new ways in the primary science curriculum. This may be because the current dominant narrative focuses on outdated views of science as one entity.

3.5.3 Primary science as one entity

It appears that science education, like the sciences, is not a single entity but instead is composed of many characteristics, including scientific knowledge, skills, attitudes, and emphasises. For each teacher the different elements of primary science that they select as important depend on their views of the purposes of primary science education. Some teachers consider that schooling, and science education, takes place in a social and political vacuum (Bourdieu and Passeron, 1977; Fensham, 1988; Bruner, 1996). Yet schools are established to fulfil many functions, and there are political demands of schooling - for example, making sure there are enough but not too many scientists. The curriculum is given to teachers, with Fensham (1988) suggesting that research and development scientists have power and influence that they utilise to maintain science as part of an elite and important field (something that Justine discusses when discussing her work). There are also social and cultural aspects, as science influences society with its technological applications, such as mobile phones and social media. Additionally, studying within the sciences touches the individual by offering some the opportunity for personal growth and satisfaction.

Mill (1843/1987) used the analogy of 'white light' to explain how things which may be made up of many factors can still appear white. This analogy has some value in the current debate, as those who shared their stories about primary science education all discussed primary science education as one entity. However, they all emphasised rather different components, in the same way that white light is in fact comprised of the seven 'colours' rapidly following one another, giving an overall effect. Mill played an instrumental role in early science and his 'System of Logic' was considered the blueprint for the early science education models proposed by Armstrong (1902). Armstrong, an influential chemist in the early 1890s, promoted practical science methods. Armstrong, along with Huxley, Hooker, Faraday and Whewell, contributed to promoting an approach to science education which was adopted in public schools (Brock, 1973) as part of their larger aim of unifying the sciences. Armstrong went on to create text books which contained the experiments that pupils should undertake in order to 'understand the common core of factual information which formed an essential part of everyone's knowledge' (Farrar Committee, cited by Brock, 1973, p.8).
How science is envisaged depends on the interpretive frame used, and the frames held by Armstrong and his colleagues signify the worth they held for different opportunities in science

education (Roberts, 1982). Armstrong thought that what a child did for himself he would remember, that motivation and interest were important, and that learning needed to be graduated, as children learn things at different ages. His curricular emphases were mainly those of Roberts' Vision I with prominence being given to correct explanations, scientific skill development and solid foundations. Armstrong's first syllabi were published in 1889 and 1890, and he lectured on the 'scientific method' extensively. His legacy was that 'until the 1960s most school laboratories resembled those devised by Armstrong at the Finsbury Technical College and Christ's Hospital workshops' (Brock, 1973, p.54). The core group (Farrar Committee) ensured that Armstrong's view was enshrined in the education process of the Victorian age. Perhaps these proponents of science sold such an eloquent story of science that it became difficult to alter, as many of their ideas can be seen in the educational ideals of present-day educators. Armstrong thought 'the teacher of the future needs to be a guide, a philosopher and friend to those being taught, not a mere trainer of parrots' (1902, p.103). The metaphors of the science teacher as guide or sage appear later in the biographical chapters and these stories provide insight (Bruner, 2004) into participants' epistemology and the curricular emphasis that is valued.

3.5 Summary

The construction of science by Whewell, Herschel, Huxley and associates can be considered as a success story. The creation of public science, with the support of both political and public agreement, has been accepted by society. This chapter has identified the historic background of many of the presuppositions in science teaching created by Whewell and Herschel and brought into education by Armstrong. The section on science education suggests that:

i) Myths about science and scientists abound because they were adopted by teachers as part of their apprenticeship and they in turn then use these impressions in their future teaching (Lortie, 1975) (section 3.5.1);

ii) An algorithm approach is used in science teaching which does not consider the fallibility of observation or how theories inform ideas (section 3.5.1);

iii) Scientific literacy was discussed and is clearly part of the narratives of primary science, but the type of scientific literacy selected varied, several approaches were discussed (section 3.5.2);

iv) Science is not a single entity but instead is composed of many characteristics, including scientific facts, skills, attitudes, and as a result there are many different visions for science resulting in primary science being like light, composed of many different factors but still appearing as white light (section 3.5.3).

As society has changed there has been an attempt to bring a Vision II curriculum emphasis (Roberts, 2007) into science education and to challenge the image of science as objective, which will be discussed in greater detail in the next chapter. I personally found it hard to change my presuppositions and the concept of there being truth in ‘public science’, even in a modified form, which has worked for me privately and professionally for a long time. However, my presuppositions in the future will be the result of a ‘conscious choice’ and not a result of an ‘inevitable conclusion’ (Feyerabend, 1987, p.1) or an outdated belief about science. Rorty (1989, p.21) explained that within western cultures this search for understanding and ‘truth’ is a human tendency, and that when attempting to find sense in one’s existence a search for objectivity is to be expected. This chapter has identified some of the contextual and historical issues that influence the current practice and contribute to my understanding of all three research questions.

The current dominant narrative that leads to the creation of the paradigm of primary science has been set out (Chapter2), alongside the history that supported the development of such a position (Chapter 3). The first research question has been investigated in these chapters. In the next chapter my perceived need for objectivity will be discussed further as research question two becomes the focus of attention.

Chapter 4: The structure and classification of knowledge

When I began to work with the life stories of the participants it became clear that there were elements within each that were similar, a love of science teaching and learning for example. However, it was their understanding of the nature of science and scientific understanding that was disparate. The research question that underpins this chapter and chapters that follow was:

- What contribution can auto/biographical narrative enquiry make to illuminating problems and or possibilities for primary science by engaging with the lived experiences of a sample of primary science educators, with reference to their own learning lives?

My challenge was how the participants' views of science influenced their epistemology and approaches to science. I also had to question my own epistemology and how this influenced my exploration into their understanding.

4.1 Introduction

I originally took a dichotomous position on the investigation of science and science education, but this chapter will follow a pluralistic approach. The need for a pluralistic approach is demonstrated by utilising Burnet's (1681) view of the stars:

> That they lie carelessly scatter'd as if they had been sown in the Heaven, like seed, by the handfuls; and not by a beautiful hand neither. What beautiful Hemisphere they would have made, if they had been plac'd in rank order, if they had been dispos'd into regular figures, and the little ones set with due regard to the greater. (Cited by Holton, 1973, p.79)

However, the hand that scattered the stars was in fact skilful, if the pattern did not have humankind at the centre of things (Holton, 1973). Whilst an understanding of Earth at the centre of the universe was replaced by the heliocentric (sun at centre) view, science is still a human-centred approach, defined by socio-cultural practices. However, I contemplated whether the social and scientific approaches to science have more in common when examined, like these stars, from a different starting point or perspective. One such starting point is to consider if knowledge can be narrative (Hendry, 2010), and this is examined using the life stories of a group of successful science educators. The approach though is personal and reflexive and makes no claims to be a comprehensive statement of the range of different possibilities or circumstances involved in the creation and sharing of scientific understanding. The first draft of this document was more than 60,000 too large and some of the sections on theories of knowledge that has been investigated for my own understanding did not make the final document.

4.1.1 Reasons for this chapter

There were three reasons why scientific understanding is important to this work. The first is that the dominant narrative of primary science concentrates on a question of limited teacher understanding (Abell and Roth, 1992; Alexander *et al.*, 1992; Harlen *et al.*, 1995). This issue, recognised in different ways by the participants, is at the heart of the issues in primary science teaching. In order to comprehend their presuppositions, I found myself examining their epistemology. The second reason is that the methodological approach used in this study originates within a sociological framework where there is no such thing as knowledge without a knowing subject (Young, 2008b). I am not adopting a post-modernistic stance that permits 'truth' to be identical to individual truth-claims or suggesting that there is no difference between knowledge and experience. I question the idea of science as rational and objective, by definition, and I acknowledge Young's point that 'what counts as school knowledge will always be contested' (2008, p. 19). The final reason for this chapter is that the subject matter of this study, the study of the sciences, from some of the participants' perspectives, is within a rationalist, empirical perspective. Most of these successful science educators hold a positivistic and stereotypical position (Abrahams and Reiss, 2010) and in order to understand their positions and my own required a consideration of epistemology.

The three different perspectives of, and approaches to, knowledge shared at the start of this chapter stalked this thesis from its beginning and resulted in an approach that seemed at times to be rather conflicted, as investigations into these different perspectives occurred. I came to this study with a realist positivist approach to science and a belief that science education was the same as the sciences, only more simplistic. However, it became clear that without unpicking the 'knowledge question' (Fabian, 2012), which is more than one question and can be defined as 'knowledge of what?' and 'whose knowledge?' it was going to be impossible to move forward personally or to examine the participants' stories of science. I am not suggesting that the answer provided here is complete but, by taking this approach, I found some answers to the questions and challenges raised within the participants' and my own autobiography.

4.1.2 Status of knowledge

There are different types and definitions of knowledge and knowledge claims. Since the time of Protagoras, debates about questions of knowledge have included sociological perspectives, raising inquiries into the cultural base of knowledge, although it would appear in the literature that this questioning was more prominent as a result of Kuhn's scientific revolutions (1962). I feel comfortable with Chesher' s stance that knowledge does exist, that 2+3= 5 is a known fact, and that Galileo, rather than the church, was correct about the movement of the Earth (Chesher, 1993, p.5). Therefore, I accept chairs, tables and clouds as part of my reality. The 'knowledge question' becomes more challenging when the nature of science becomes part of the question and each participant's presuppositions and motivations were informative. The question 'what we know about how they know what they know' (Fabian, 2012, p.443) was useful in interrogating the participants' views, (Chapters 6-9).

In many systems, it is possible to identity a dichotomy between the realist (rationalist) and the social forms of knowing. Related dichotomies have many names and include: the normative and empirical; the synthetic and analytical; and the monistic and non-monistic view. However, I think it is more than a dichotomous argument between rationality and social activity. As a result of this study, I favour a narrative construal of reality (Bruner, 1996, p. 147). Bruner suggested that humans live in a sea of stories but are unable to recognise this, in the same way that fish are the last to discover water (ibid). Whilst *Thought Experiments* in science are accepted as a type of narrative (Cartwright, 2010) I propose that it is through narrative that understanding is created. In order to develop this argument, I examined several definitions of knowledge (only some are presented here) which led to the development of a simple model, and finally my realisation that theoretical and practical understanding of science entails an interplay between rational, social and psychological elements.

4.2 Definitions of knowledge

In trying to unpick the 'knowledge question', I recognise that there are different definitions used. Knowledge can be a state, an activity, or a possession (Fabian, 2014 p. 444). I take 'state' to mean having knowledge as against ignorance; 'activity' as the acquisition of knowledge, or the processes of acquisition; and the 'possession' of knowledge to refer to the body of knowledge or the known.

Other definitions are that knowledge is what gives life order (Ploktin, 1997), and requires an internal feeling and an external event. Knowing includes emotions, knowledge from others and knowledge from senses (Ploktin, 1997). Knowing is a relationship, where knowledge concerns an association between the knower and the known (James, 1909). At a simplistic level, in primary science, the knowers could be the teachers and their students and the known could be the primary National Curriculum (DfE, 2013) – although perhaps the ultimate knowers are those who designed the curriculum in the current format, deciding what was important for this stage of primary children's science education.

The curriculum for primary science, also called the programme of study, defines what all learners should know and understand and that all teachers in English state-maintained schools legally should follow. The current science curriculum (DfE, 2013) defines the known as existing independent of the human knower and the idea that senses are needed in order to access to this knowledge. This empirical approach is not new in curriculum terms. The National Curriculum is a statutory requirement in English primary schools defined by sections 78, 79 and 80 of the Education Act (2002, pp.52-57). In the programme of study, knowledge is defined as a 'body of key foundational knowledge and concepts' (DfE, 2013, p.3), whilst the doing of science is termed 'working scientifically' and identified as 'nature, processes and methods of science' (DfE, 2013, p.4). The DfE (2013, p.4) document identifies that working scientifically 'should not be taught as a separate strand.' This is something that I will return to when undertaking analysis of the biographies of the successful science educators, as the importance of working 'like a scientist' is thought to be more significant than the facts of science, by some of the participants.

Stehr suggested that 'Knowledge, [is] not something that is so but as a generalised capability to act on the world, as a model for reality, or as the ability to set things in motion' (Stehr, 1994, cited by Adolf and Stehr, 2014, p.1).

The definition that accepts there can be no knowledge without a knower is an interpretation that focuses only on an individual's constructive activity and is not something that exists outside the knower (Von Glasersfeld, 1989). This differs from the opinion that there are things lying about in space, regardless of whether there are knowers to see them (Gurney, Myers, and Podmore, 1886). Taken to extremes, the presupposition that there is nothing without a knower would lead to the view that the planets are 'cultural objects' (Lynch, Livingstone and Garkinkel, 1983). However, Nagel suggested that whilst physical objects can be represented by sensory perception, the 'physical things can also cause effects without human presence and can exist without causing any perceptions at all' (1986, p.14).

The confusion between knowing and the knower is crucial to this study and arises because of a misunderstanding between 'ideas of real or theoretical objects and between physical and intellectual activity' (Matthews, 1994, p.142). There is a suggestion that this confusion was brought about by a shift in emphasis from rote teaching to the adoption of a constructivist approach (Duschl and Grandy, 2013). However, although empiricists would identify that science is about sense data, others perceive science instead to be about how to transform these sensory inputs into theories (Dewey, 1929; Nagel, 1986).

For me, the debate about knowledge was all about complexity: 2+3=5 is not complex; functionally, chairs are not complex, but compositionally chairs are a completely different matter. The misperception about the processes of the sciences formed part of the debate in Chapter 3: science as understood through the lens of quantum science bears little relationship to the informed and systematic portrayal of science by most participants, who tell a story of science where ideas build upon each other through time. As discussed, this cumulative story was disrupted outside education by Kuhn, (1962), yet within science education science is about certainty and not probabilities (Kind and Osborne, 2017) even though aspects of the sciences are fundamentally about probabilities; for example, the answer to whether exposure to sunlight would cause skin cancer is not a simple cause and effect relationship. Science education appears to focus on simplistic understanding of the nature of scientific understanding that does not include cognitive, epistemic and social practices: In order to involve all learners in science this complexity is essential.

The ideas about how scientists turn ideas into theories and test these against their sense data differ from Galileo's falling masses, which as examples of *Thought Experiments* were never about real objects falling (Cartwright, 2010) and existed only in an ideal mathematical world not the real physical world and therefore could not be tested. This difference, as will be acknowledged later in the biographies, is not part of the consciousness of some primary science educators. Science education is based on Herschel's idealistic one method perspective of how science understanding was created, yet the sciences instead recognise that: the theories that are held influence the recorded observations; there is more than one answer possible for many of the observations conducted (Feynman, 1967; Feyerabend, 2011); and that the sciences are fallible (Abd-El-Khalick, Bell and Lederman, 1998). Although current quantum scientists find no place for the objective observer, this does not mean that everyday objects do not exist. Nor is it logical to make the link between the human ability to create knowledge and the premise that all knowledge claims are therefore unfounded; a far more nuanced understanding is required.

Perhaps the empiricist, traditional view of the sciences that underpins the primary science curriculum is partly at fault for promoting simplistic views, for example that objects lie around waiting to be tested or 'to fall on someone's head' (Matthews, 1994, p.152). However, this is not the whole explanation, as learners also need a common language in order to communicate with others and explain their theories of science. However, pupils do not construct this language independently: they learn it through education, in conjunction with others. This initiation is not only into the world of the observed but also into the world of historically informed and agreed science. Facts and entities contained in some scientific theories cannot be tested, and other theories, such as

Copernicus' orbiting Earth, disregard common sense. Yet as can be testified by quantum theory, common sense and the use of empiricism play little part in the development of scientific understanding (Gribbin, 2012).

A common-sense approach would dictate that all things come to a rest and will stay that way unless acted upon, and yet Newton's second law would contradict this (Bohn and Peat, 2000). The sciences are a community of practice and the information they create is passed on; therefore, in this sense, there can be knowledge without the knower. There are new ways to generate scientific knowledge as demonstrated by scientists who, at the start of the twentieth century, were debating the existence of atoms and genes, and now manipulate atoms and conduct genetic engineering (Duschl and Grandy, 2013). The problem is that these changes, where scientists and engineers no longer just observe phenomena but instead produce them (ibid) is often misconstrued by science education. It appears that the understanding of how knowledge is created in school science exists in a very particular way, so a further examination of the rational and social divide is required to ascertain if 'only what can be understood in a certain way can exist' (Nagel, 1986, p.15).

4.2.1 Understanding developed from sensations

The divide identified above between different beliefs about knowledge is a philosophical one, but, whether a view of knowledge is sociological or rational, in order to be knowledge, it must be something that can be articulated and shared. The empiricist scientist Mach (1897) alleged that knowledge could only be understood in relation to humans and their sensations, that sensations are the ultimate phenomena, and knowledge of these was the only way to gain scientific knowledge. In contrast, the sociologist Young (2008b) defined knowledge as more than just experience, even if the experience argument has compelling power, arguing that schools should be providing an understanding of the world for all students while accepting that some domains, such as science, are viewed as more powerful.

Understanding of science is created, science has a structure, and scientific knowledge and skills are known because they are represented in a narrative form to other humans, although there is no way of knowing if they mirror nature (Rorty, 1982; Jammer, 1966). However, scientific knowledge is not just a mere accumulation of facts (Boulding, 1995), as the communication of facts to others is accomplished within the context of the currently-accepted story. As the environment, as a whole, is too complex (Reed, 1992) only specific observations take place out of all possible observations. Therefore, theories generated from observations do not directly relate to sense data but instead to mathematical models generated by the mind (Nagel, 1986), which was why many of Galileo's critics had problems with verifying his experiments (Naylor, 1974). Consequently, the tacit knowledge that a society develops results from the sharing of only some identified elements of the environment. This results firstly because the observers gather only selective data from the environment, and secondly because humans perceive and act as an organised group, not just as individuals, so communication within a society is only ever partial (Reed, 1992). This ecological realist approach is discussed below.

4.2.2 An ecological realist definition

An ecologist realist approach is not the same as the ecological psychology approach (Barker, 1968), which recognizes that phenomena studied in the environment are different from those that can be isolated and studied in a laboratory. The ecological realist approach links both the rational and social elements and emphasises that human behaviour differs according to the setting (Reed, 1992; Gibson, 1966). As the environment influences the behaviour of humans, it is therefore important to understand the whole environment. I would suggest this is particularly true for the complex environment of a classroom and could explain why Ofsted identified that 'teaching in science was at least good in around three quarters of the schools visited. This proportion is higher than for schools' overall performance in teaching and learning' (2011, p.4). This suggests that primary teachers teach science better than they teach other subjects and/or that their lack of confidence and understanding was not impeding their ability to teach (Lunn, 2002).

There is agreement that empirical observations and sensations are not the same as the understanding created from them (Dewey, 1903; Nagel, 1986; Reed, 1992; Hacking, 1999). It is also established that through experimentation and discussion, these observations become transformed. From this perspective, there cannot be knowledge without a knower, as the practical experimentation is always constrained by the theory (the story) that the perceiver embraces. The primary experiences that the observer gains from the environment can have colour, texture and smell (primary sensations), but when they are transformed through discussion, experimentation and theory, they become framed and differ from the sense data (Dewey, 1929; Nagel, 1986). When the primary sensory experiences are reflected upon, they become the secondary abstracted, transformed experiences of the 'theoretical world', and this is the *knowledge process* (Dewey, 1929). Primary science, however, does not teach that sensory inputs are transformed by this process but rather that science creates complete information and is the route to understanding nature. It is therefore not surprising that many find science difficult to comprehend.

One role of science education is to test this transformed scientific understanding back in the world by the process of experimentation (Dewey, 1929). One outcome of this notion of transformation is that the knowledge created is temporary and may not exist independently of reality. Using water as an example, the primary sensory experience of water is that it is wet, useful, can be drunk, is colourless, odourless, etc. and yet it can be transformed, not only into a gas or a solid, but also into abstract chemical symbols. This transformation is through language and signs, turning water to a molecular substance with a formula of H_20 that changes state at certain temperatures and when transformed in this way, many of its primary properties become irrelevant. One molecule of water is not wet, wetness emerges when there are many molecules (Du Sautoy, 2016) and the simplifications in science can result in the notion that they have the answers to all questions. In primary science, teaching emphases primary sensations, so there is selective perception and a focus on things that allow coverage of the curriculum. This results in partial understanding and a curriculum that communicates a narrative of the 'exceptional' scientist, a view shared in chapter 6. In Chapter 8 science is viewed as is an inbuilt way of thinking, which is a different explanation for what makes science possible or why humans carry out science. This narrative is that knowledge development and communication is part of human evolution.

4.2.3 The evolutionary argument

In the evolutionary argument there is no specialness of scientists' brains, as scientists are no different from other people: they have the same type of brains and use them to find out about the world with the assistance of culture (Gopnik, 1996). The idea of growth of facts and skills being part of the evolutionary process is growing and has support in different ways by a range of writers (Dawkins, 1996; Gopnik, 1996; Plotkin, 1997; Geary, 2005; Boyd, 2010). Human understanding is achieved through the creation and use of signs and symbols (Hacking, 1983) alongside the system of rules that operate these representations and are the foundation of cognition. These representations and rules can change over time and are examples of both logical and psychological structures which can be influenced by people but can also operate outside any social community (Gopnik, 1996). The process of evolution provided humans with ways of constructing and manipulating both the rules and the representations to provide a veridical view of the world. Whether it is how these representations and rules are both structured and created which provides science with its epistemological potency is unknown, although perhaps science gets it right because it uses psychological devices designed by evolution precisely in order to get things right (Gopnik, 1966).

The extraordinary amount of learning that human children accomplish in their extended period of childhood is thought to play an important part in evolutionary success, alongside the human ability to adapt to a range of environments and conditions. Plotkin, using the term 'the Darwin machine' (1997), explains how random generation of variation allows for new possibilities. However, randomness is an intrinsic function of the brain (Hobson, 2004) as it tries out new ideas, alongside the selective retention of patterns that have worked in the past. An important feature of this mechanism is the ability to understand patterns, because without patterns and structure, this randomness would result in chaos (Boyd, 2010; Du Sautoy, 2016).

Scientific activity appeals to the self-motivating cognitive preference for pattern-making, a process undertaken by children as well as scientists. The testing and communicating of ideas and theories within the scientific community provides feedback, and as humans are self-reflective, this leads to the formation of new ideas. Gopnik (1996) suggests that scientists are different from non-scientists, because they, like children, never become bored with searching for patterns as they carry out their exploration of their world. This argument supports the science education narrative of the child as scientist, proposing that young children's curiosity is only found in the domain of science, or that everything is science. All these approaches are very narrow ways of looking at knowing and are not supported by research (Boyd, 2010). Dewey (1915) instead suggested that the young assimilate the view of their elders and what is possible is determined by what is expected and approved of.

Natural curiosity and play are an important part of learning and the sciences provide the opportunity to tinker, refine and continue to create. For some, including the participants, this is intrinsically motivating and as the sciences involve an external form of testing, using other humans' minds to evaluate whether an idea or theory is worthy of debate, which might lead to external recognition. However, if the community does not value this new idea, it will vanish without a trace. The sciences utilise a range of formats and those who work in the sciences can also change these formats. Yet even new practices and approaches use current agreed scientific ideas and do not start from scratch because if the tacit knowledge of the society was ignored It would be considered a waste of previous energy and would make little sense from an evolutionary perspective.

Scientific knowledge is created by a process of cumulative novelty, but like all evolutionary practices it scrabbles around in the endless possibilities of space until the solution is suggested (Boyd, 2010). The creation of new understanding is more intrinsically motivating than amassing what is already known because new ideas can generate acclaim, which is important within the sciences (Wolpert, 2000). New ideas are sometimes achieved by adding only an element to a previously known idea or more rarely by a complete theory change (Kuhn, 1962; Lakatos, 1972). The debate is about the mechanism that is the driving force; with Boyd (2010) suggesting that the changes come from human need. Plotkin (1997) instead would suggest it is by random adaptations and he viewed intelligence and rationality as such adaptations, with science itself being a type of adaption. Yet Hurd

(1997) suggested that this adaptive capacity is primarily a learned one. For Plotkin (1997) there is no fence sitting in science because it allows the creation of novel solutions for a changing world. However, there are many possibilities in science and the outcome selected is only ever one of the many that were possible.

The evolutionary argument is based on cooperation, as working collaboratively has been shown to offer more success, although this challenges the idea of the isolated scientist and the 'selfish gene' (Dawkins, 1996). However, Dawkins himself suggested his book might just as easily have been called 'the cooperative gene' (1996, xiii) as success ensures the health of the whole population and not just the individual, even if the evolutionary tale has been the survival of the fittest. Cooperation is the attribute that has probably led to the growth of human intelligence and the development of an ultra-culture (Wilson and Wilson, 2007), where time for thinking beyond the here and now was the outcome of working together. This led to the theory of mind, which alongside the compulsion for creating stories, improved the human ability to think (Geary, 2005) as well as predict what others might be thinking. Both processes are helpful when trying to stay alive and judge who is friend or foe. Scientific developments are now undertaken by big teams who cooperate (as discussed in section 3.3.2) and all those who tell their story in chapters 6-9 discuss the importance of others in their science lives.

Whether Gopnik (1996) is correct in her assumption that scientists are members of society who have remained like children in their quest for answers is debatable but will be returned to later (Chapter 8). Ryan and Deci (2000) advance a reason why children stop being curious, namely, that maturation brings about increased social pressures and as a greater number of roles must be assumed by the child. These greater responsibilities influence their actions regardless of the sources of their motivation and as a result they stop being curious. Yet I wonder if those who are not encultured or assimilated into the world of science (Aikenhead, 1996) find scientific activities make little sense, and resulting in other domains being preferred.

The literature within the area of evolutionary epistemology is immense and is only touched upon here. What is clear is that the human brain does not just tell stories of the past, but it also makes up stories that did not happen and can also use a story function as a simulator to try out ideas before committing to them in real life, for example in experiments. The storying of a spider by young children was utilised by Ellis and Kleinberg (1997) to demonstrate how telling stories not only encourages recall but also the generation of comparative statements, which could enable additional scientific observations to be made. This story approach was used by Gell-Man when he created Quarks which then enabled greater experimentation to occur. The narrative process is part of the mechanism by which the development of understanding can transform the self. Transformation is touched upon in this work, as many participants saw their involvement in science teaching as having a transformational characteristic for themselves and others. They were transformed when they were encultured or assimilated (Aikenhead, 1996) into the world view of science. Such activities provide the capacity to illuminate or transform the human experience, and without this transformational capacity, knowledge remains as mere information to be forgotten.

A scientific narrative requires a world view (frame of reference) as demonstrated by the following example using the different models of the solar system, where two statements can be made: 1) The sun moves across the sky; or, 2) The sun does not move. Both these statements can be correct dependant on the frames of reference used (Goodman, 1979, p.2). From my position on the Earth the first frame of reference is observed daily. From my understanding of the sciences and an understanding of history (an encultured position), the second frame of reference is accurate. Daily observations of the movement of the sun do not connect to accepted scientific knowledge. The transformation from position 1 to 2 was not a straightforward process for Copernicus or for children today. All knowledge creation requires transformations and identifying the need for a pluralist account of knowledge has transformed my outlook and was key to creating the model of knowledge presented below.

4.2.4 Summary of definitions

In this section, different definitions of knowledge were presented. The state of knowledge, knowing or not, is developed through the view of the known and the knower. I questioned the role of sensations in the creation of understanding and defined the ecological and evolutionary models of knowledge. In the evolutionary argument, the cooperative nature of human society to enable science to develop and science as an adaptation was discussed alongside the role of stories to enable simulations prior to action. The section ended with the definition of knowledge as transformation, a key feature in many of biographies that follow

Working with others provided a catalyst to question what I knew about the sciences and knowing. The section was included because the biographies illuminated problems and exposed different presuppositions and motivations that were supported by different views of how knowledge was created. This struggle between different forms and types of knowing, only a section of which is presented here, was the foundation upon which a model was developed that I later used within the biographies. The iterative process is described in more detail in Appendix 1.

4.3 The structure of knowledge

Several models were examined to visualise the creation and questioning of knowledge. In beginning the task, I used a framework proposed by Bernstein (1999) alongside personal experience from working with STEM based professionals. I became interested in this area because the participants held differing views and in order to try and understand meaning it was necessary to understand how this meaning was produced.

4.3.1 Horizontal knowledge structure

There are many ways of defining types of knowledge although a structured, dichotomous approach has been favoured by many writers (Polanyi, 1958; Bourdieu, 1990). Knowledge structures generally consist of an everyday and a contrasting specialist form of knowledge each creating belief systems with different names. In the everyday knowledge groupings, whether they are called functional, practical, life skills or pathos, the knowledge is regarded as common to all the community. The other form of knowledge is described as specialised, expert, sacred and symbolic, and accessible for either specific groups or by having institutional representation.

Until the 1980s, Bernstein suggested that the emphasis of educational research was on pedagogic transmission and acquisition of knowledge, rather than questioning what was being disseminated (Bernstein, 1999). He suggested that this romanticised some forms of knowledge and stereotyped others and, as a result, Bernstein considered two ways of looking at knowledge - the horizontal (everyday knowledge) and vertical (specialised knowledge) discourses. His model demonstrated how these different forms of discourse varied. Taking his notion as a starting point and working with the participants I adopted a vertical and horizontal structure, but I found that this did not answer all my questions, see Appendix 1.

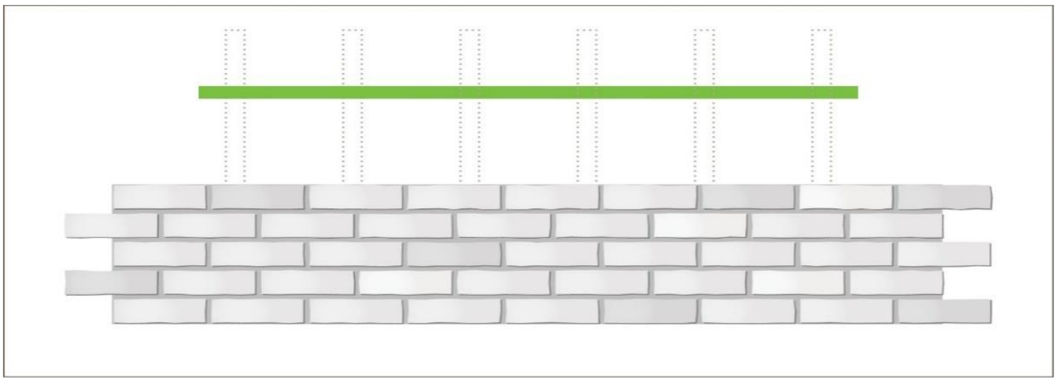

Figure 1: Knowledge in the horizontal, everyday discourse

After examining Bernstein's different models of knowledge creation, I decided to use pictorial representation, with some alterations. (Figure 1). This model depicts everyday knowledge as a horizontal layer portrayed as fragmented, segmented, multi-layered bricks. This could be thought of as, for example, all the everyday facts, with 2 + 3 = 5 (Chester, 1993) and other basic number systems in a brick, and skills, such as how to clean teeth in a different brick. The number of bricks increases as knowledge valued by society is understood (Dewey and Dewey 1915) and results in the development of everyday knowledge. Within a culture there is some consistency, so there would arise common horizontal discourses because of the common history and something Bernstein termed 'the common problems of living and dying' (1999, p.159). Whilst the facts and skills are consistent within cultures, they can be contradictory across contexts, so what is a fact or skill in one culture might not be in another, as demonstrated in debates about western and indigenous types of knowledge demonstrates (Aikenhead, 2006). The position and inclusion of bricks will differ in different societies. As civilisation has become more advanced the gap between what the young know and the concerns of adults, widens (Dewey, 1915). For a member of a cultural group to be considered successful some fundamental bricks are required, and this fact, skill or information (knowledge) can be gained from first-hand experience or by being taught. These are shown as blue layers at the base of the diagram (Figure 2).

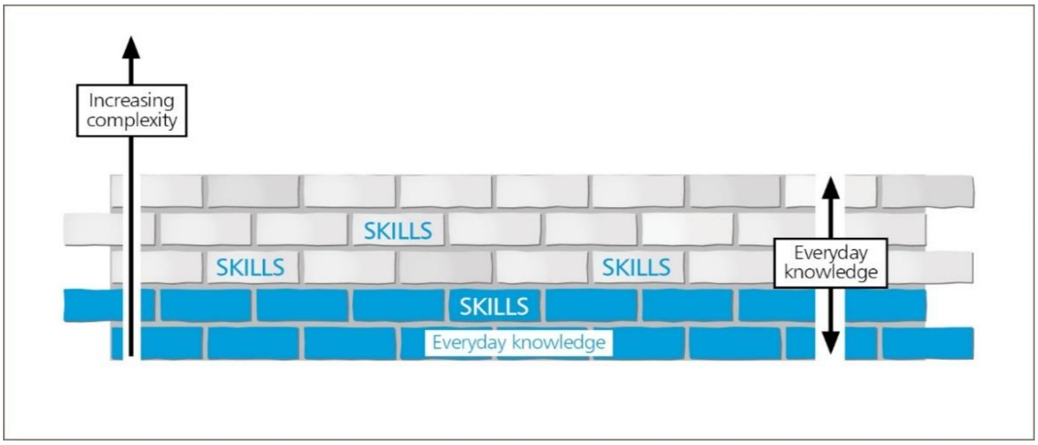

Figure 2: Fundamental bricks in the horizontal knowledge structure

Within these horizontal bricks, is the knowledge that each person in a culture has access to; the reservoir of culturally shared knowledge - what the community at large knows (Bernstein, 1999). In my research, it appears that what the community knows is dependent on many factors, and as a result each person develops their own set of bricks. The prescribed curriculum at school will determine what 'the school community is expected to know.' Prior to schooling, the family and cultural capital (Bourdieu, 1990) influence the acquisition of bricks. A suggested process for this acquisition will be developed below. Everyday understanding is linked to the specialised facts, skills or information of different domains and the acquisition of both more specialised and common bricks will be dependent on personal and social factors.

The acquisition of facts, information and skills is ongoing and does not stop in childhood and is always influenced by society. In the case of primary science educators, the schools and teachers they have worked with in and the status of science in that institution (Mulholland and Wallace, 2003; Wellcome, 2017) also influences the bricks in both their vertical and horizontal collection. In addition, each person would have their own repertoire dependent on personal experiences (biography, presuppositions and motivations).

The horizontal bricks (Figure 1 and 2) do not link and learning in one segment may not connect to learning in another. Sometimes this is because skills are not related - for example, 'learning to tie shoe laces is not linked to learning to use the lavatory' (Bernstein, 1999, p.160). Alternatively, specific learning links are missing between these contexts: for example, primary children rarely transfer their understanding of graphs from science into mathematics or *vice versa*. This situated nature of learning is dependent on material and tasks (Bruner, 1996, p. 132). Teaching helps learners identify the links between these segmented learning activities (Bruner, 1978) and the whole community develops a set of facts, skills and information using modelled behaviours expected and valued by that community. The 'doxa' (Bourdieu, 1999) can influence and be influenced by the addition of bricks or changing bricks. In some subcultures there will be common competencies that all should learn, and these are 'contextually specific, context dependent, embedded in ongoing practices' (Bernstein, 1999, p.161). In primary science education, these might relate to views of science.

Each primary science teacher has a place within a community and will have a nucleus of common community bricks, created not only by their training but also by their prior experiences. Differences will exist because of history, contexts, biography, experience and interests. However, if isolation happens to either an individual or a community, for example by focusing on limited aspects of the curriculum then the social base for both the individual's and the community's reservoir is reduced. In the current debate, this isolation could be the result of a lack of importance of science teaching or caused by the primary teacher not having the opportunity to share and develop their ideas.

The horizontal structure also comprises practical skills and these skills differ from those found in the vertical layer which is more specialists in composition. With technological advances, some things can change, for example previously using a mass spectrometer would have been found in the vertical layer as it is not an everyday skill for most of a community but now this equipment is found in some secondary schools and therefore is no longer the preserve of scientists. In the same way, the thermometer was a disputed object of research in the seventeenth century but became a ‘taken for granted’ instrument for chemistry and meteorology by the late eighteenth century (Golinski, 1998), and is now used in everyday life. Such technological advance is not a new phenomenon, but a thermometer only requires the skill of reading numbers on a strip and an understanding of how these numbers relate to other numbers - whether 38 degrees Celsius is too high a number for a baby’s temperature, or that 100 degrees Celsius is the temperature at which water boils. Many in society have developed the skill of reading the numbers and can now use this technology. However, knowing how the thermometer works is something very different, so there will be some skills that use technology that provide access to information but without the understanding of how the systems works; these will be found in the everyday layer.

It is proposed that as understanding develops, the horizontal structure will contain more layers and where the bricks relate to more abstract, everyday knowledge these will be found in the higher layers in the wall. Teachers will provide these science blocks of learning from the requirements of the National Curriculum. Learners of all kinds can add to their bricks themselves by using books and artefacts of society.

4.3.2 Vertical knowledge structures

It is in the vertical aspects of the model that the ideas differ most from those of Bernstein who separated the sciences from the social sciences and humanities. In Bernstein’s model the vertical structure was not segmented, although he suggested it did contain ‘levels of meaning which are linked by ways of thinking and specialised symbolic structures of explicit knowledge’ (Bernstein, 1999, p.161). These symbolic structures are the ways of working, the methods and approaches that underpin the perception of the environment. Bernstein identified two aspects of this vertical discourse - one that focuses on theories and the other focused on language systems. I have devised a different model focused on my understanding of how understanding is created as a result of working with the participants.

Bernstein viewed the vertical discourses as a triangle with abstract levels of knowledge at the apex. However, in Figure 3 each of the vertical columns represents a community that creates its own set of discourses. Using this structure allows for greater opportunities to see links between different forms of skills, information and facts and how some aspects, such as the history of thought identified in green (Figure 1 and 3), can cross many subject domains.

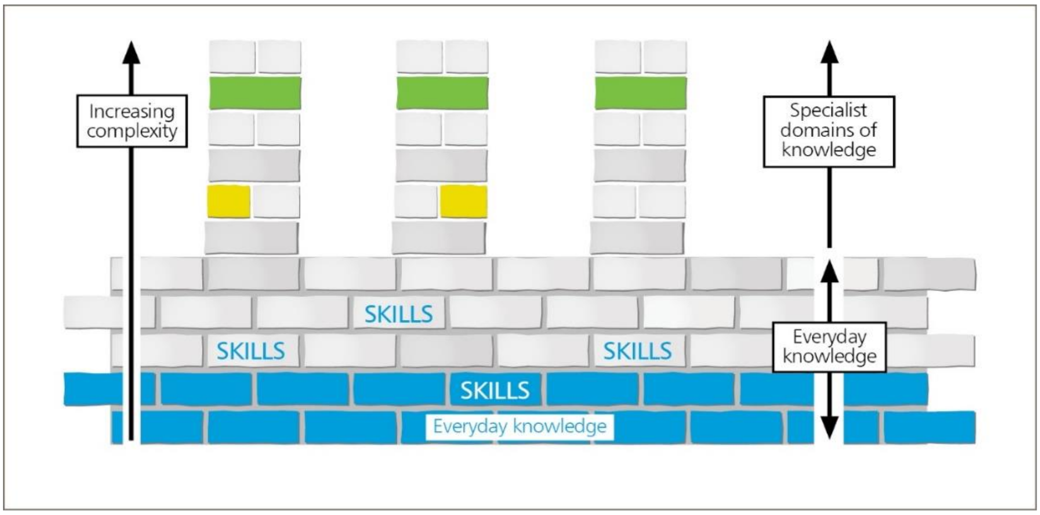

Figure 3: The horizontal and vertical structures of knowledge

The philosophical nature of this green line suggests it is not everyday knowledge, although over time elements may become part of everyday knowledge. The yellow blocks represent specialised knowledge which is found within more than one domain, for example understanding baryons in chemistry and physics.

Presenting different subjects as separate vertical structures negates the need to rationalise some domains having more value than others, so that, for example, the suggestion of sociology having less value than physics becomes unnecessary. Within each vertical structure, each domain has its own system for communication and identification of its values. This is the subject's 'gaze', using Bernstein's (1999) terminology and the dominant perspective of those in the group determines this 'gaze'. Over time, the accepted view might change, but the 'gaze' is valuable if there is a dispute - for example: if a choice of theory needs to be made; if a special interest group wishes to challenge the current practice; or if there are external pressures from society to make changes to what is considered as knowledge (Gadamer, 2004). In primary science these changes were apparent in the development of the Primary science curriculum (DfE 2014) where the initial draft documents did not include working scientifically. In science education the 'gaze' preventing change is 'heavily dependent on unreconciled philosophical clashes that hinder progress' (Dillion, 2009, p. 202).

Reflecting on the case studies and literature necessitated an approach where different forms and types of understanding could work together and for different views to exist at the same time within different communities or domains. I viewed the horizontal areas as the skills, facts and information the whole society has access to -termed common knowledge. The mature and knowledgeable of a society often know far more than the wider group but no one is specialised in all aspects, as shown in the model as multiple vertical sections.

The horizontal and vertical structure of knowledge (HVSK) model initially helped me to understand aspects of different types of knowledge. The HVSK is a type of knowledge classification system but as this did not answer all my questions, my next step was to examine knowledge creation and after several prototypes, the Sphere of knowledge Creation (SKC) was devised (Figure 4) see appendix 1 for details of this iterative process. The model was developed as a result of working with the participants, reading research about the differences between science and science education (Chapter 3) alongside the concepts of aspiration and biography that was discussed in Chapter 2. The SKC helped to explain personally the existence of both public and private views of science (Holton, 1973; Eisenstein, 1933). The SKC is the private learning environment of the individual within their community: this is the area of knowledge creation (Einstein, 1934) and it begins from very early experiences, although, initially, the presuppositions are few and motivations are concerned with basic functions of life. In an evolutionary model of knowledge, the human child's extended period of childhood, compared to other animals, provides opportunities for others to support their learning ensuring they are suited to their ever-changing world (see section 4.2.2). Knowledge and skills are developed as part of this mechanism of survival. Public policy and society at this stage have influence via care givers/educators who promote what society values. The narrative of the curious child is common (Byrne *et al.,* 2015; Ellis and Kleinberg, 1997; Ofsted, 2015; Rocard, 2007) and as the individual grows and develops, skills, facts and information is developed, and additional bricks are added as different opportunities occur.

The individual who is developing their learning is found at the centre and whilst they act within the world of established ideas, they also play a role in creating new ideas. Each individual shares ideas and thoughts as part of the community to which they belong, using the theories and ideas that are typical of the current knowledge system of their time; they act *in* the world of knowledge as it currently is. The narratives of their domain inform the way the world is viewed. However, the individual is also able to act *on* their world (Figure 4). All participants in this research had home lives which nurtured them and enabled them to access the skills, facts and information of their society and to grow intellectually. I am aware that this is not universal from my work as a teacher, and Justine recognised this when describing a child on a train in Chapter 8 (see section 8. 4.1).

In order to examine this model each of the four elements will be discussed in turn. It should be noted that all examples are related to science because this model was created from the science life stories, although they may have a more general application. For an understanding of the iterations of the model see Appendix 1.

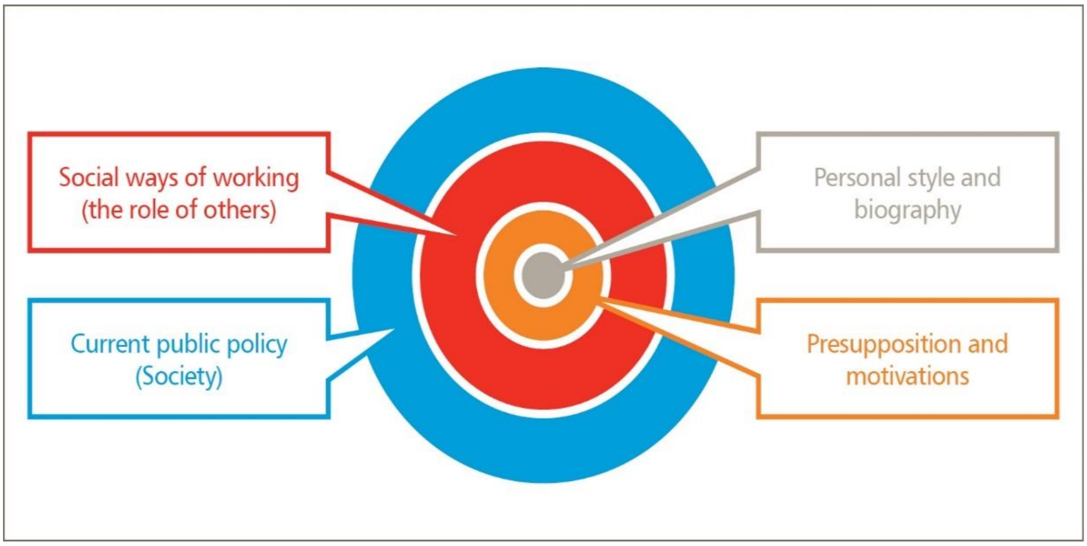

Figure 4: The Sphere of Knowledge Creation (SKC)

4.3.3 Personal Style and Biography

As the individual grows and develops (not just in childhood) they gain access to an area (areas) of specialised understanding. The successful science educators are part of a community of practice, in the community of knowledge, which influences the individual in a variety of ways. Initially, the individual's knowledge and understanding are influenced by the ideas and the prevalent 'story' within their domain, as the individual is acting *in* the world. These local narratives influence the dominant narratives and eventually become the accepted narrative of the society (Lakatos, 1970; Kuhn, 1962).

The personal style (personality) and biography of the individual exerts a major influence. Newton sought power, political influence and authority and these needs influenced his decisions, but his belief in God also affected his theories and views**.** Einstein's early biography resulted in his creation of the theory of relativity and his personal style and circumstances meant that the social working of the profession at the time had less of an influence on him. As a result, his influence *on* the world was greater than the influence of his community upon him. He published the results of his work in 1905 but it was not until 1921 that he received the Nobel Prize: new stories require time to change the old or evidence is needed to support them as demonstrated recently with the Higgs Boson.

Personal style and biography influence the theories held, and different groups bring with them diverse ways to view the world: 'not all people 'know' in the same way' (Stanfield, 1985, p.398). An example of not knowing in the same way was exposed when female scientists who were researching primates changed the narrative of primate behaviour that had been told by previous, mainly male, researchers. The change was from one where there were ‘dominant males’ to a story of behaviour that revolved around ‘making friends’ in order to gain reproductive success (Kitcher, 2002). This demonstrates that different groups interpreted the sense data of primate behaviour within a different frame and created a different theory (Kitcher, 2002), and this friendship theory is still accepted today. These aspects of influence are represented in the sphere by both presuppositions and the social ways of working. For any individual the effects of these external factors will differ, and it is unlikely for anyone’s sphere to be identical to others. The influence of the factors represented by the rings varies over time and the diagram (Figure 5) is an example of how this might happen. The SKC is influenced by different communities, for example public policy might have a greater influence on some communities while the individual in some cases will have a greater impact on their knowledge creation than any external factor.

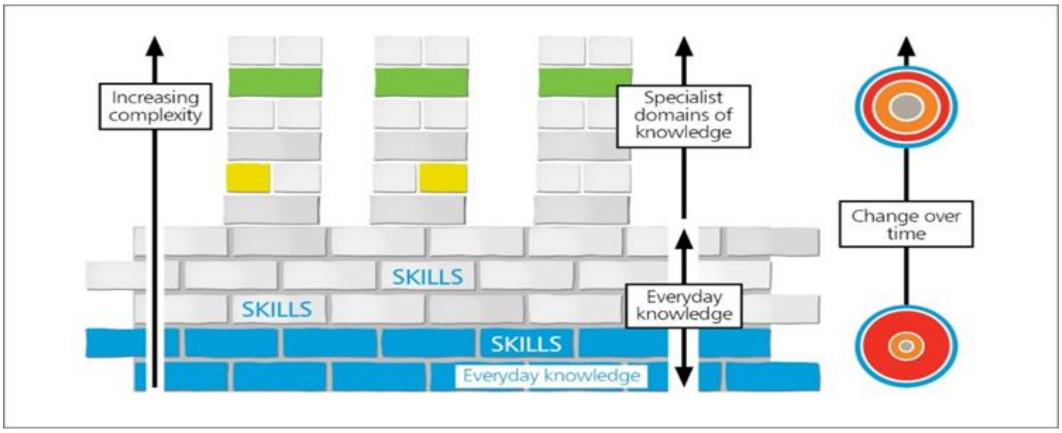

Figure 5. How the sphere changes

Generally, the personal biography of the individual or group is influenced by the social ways of working, ‘what we all know’, and by other colleagues working within the field. These social factors reflect what the core set of those working know and trust (Collins, 1985). Biography influences occupational and educational choices, (Eccles and Wigfield, 1995) but as in my own story (Chapter 1) it is the personal feeling of mastering and understanding (Marsh and Shavelson, 1985; Kjærnsli and Lie, 2011) that appears to influence more than home, parents’ occupation or science teaching.

4.3.4 Presuppositions and Motivations

An individual accepts the currently-accepted narrative of their domain, but this can change as the individual is also acting *on* their world, bringing their presumptions and motivations to their sense data. The presuppositions and motivations of the individual influence ‘what is possible’, how people think, feel and act as well as how they react in predictable ways (Cobern, 1993). These presuppositions are controlled by beliefs which influence how experiences are organised and whether things are accepted as true or not. There are many presuppositions of science, but a common one is the exaltation of positivism (Ogunniyi *et al.,* 1995, p. 818). Presuppositions have also been called worldviews by some writers (Cobern, 1993; Aikenhead, 1996; Hansson, 2014) and can be described as how the world is understood at a fundamental level. Presuppositions involve thoughts, emotions and behaviour and influence whether science is a domain that is accepted and considered "for me". All the successful science educators accepted science as their domain and therefore might argue that science has no presuppositions (Hansson, 2014) as it is the only way the world can be. All the successful science educators demonstrated several presuppositions that reinforced their view of science and how it should be taught.

The presuppositions of science were introduced in chapter 3 when the differences between science and science education were explored. As previously discussed, (see section 3.4) many science text books and science approaches offer a simplistic view of the sciences. For those who hold a science worldview the world can be categorised as self and non-self, with the sciences encompassing all that is non-self in an ordered, regular way: this non-self is called Nature (Hansson, 2014). The presuppositions that are held, either consciously or unconsciously by teachers, influence the type of information they then provide to pupils, who might not view the world in the same way.

Listening to the successful science educators' biographies highlighted that there were a range of motivations for their actions; some were extrinsic but there were also intrinsic motivations where science provided a means of satisfying individual curiosity and happiness - an endogenous capacity of humans. Justine, for example, loves the way science makes sense and this view of science as a way of ordered thinking, is the ultimate motivation for teaching science (Dewey, 1910). The world is complex (Reed, 1992) and therefore any individual will identify with only certain aspects of the available data. Individuals have also been found to change their presuppositions after grappling with the things the material world hurls at them (Pickering, 1999). However, the intricate and powerful knowledge that develops is the cumulative product of multiple instances of individual knowledge, 'which, as knowledge, can be understood without reference to social interactions' (Longino, 2002, p.575). In the current case this is canonical knowledge of the sciences.

As will be demonstrated in the biographical chapters, there are many who work within any particular field so there will be varying presuppositions about science and motivations for science teaching, and only 'outsiders' will imagine those within a domain as an united stereotype.

4.3.5 Social ways of working

The social ways of working (the role of others) is pictured initially as large with the influence of others playing a vital role in all the biographies (figure 6). The role of supportive others begins in infancy and influences not only cognition but one's future ability to develop ideas about external values and expectations (West, 2014). Only Stephanie discussed her early childhood and family expectations explicitly, but Justine makes it clear that the young child's ability to explore the world is enhanced if interested adults are present.

The influences of society were examined in more detail: stories or beliefs; the role of language; the current ways of working (how we do things); funding and recognition (capital) Bourdieu, 1990); and equipment (Figure 6) were important. An individual will not progress without support, recognition, and being able to speak the language understood by others within their wider community, which might be alien to the rest of society. Later this knowledge must be communicated in particular ways, cited by others; otherwise that knowledge will not be valued or accepted by society, (Bohn and Peat, 2000).

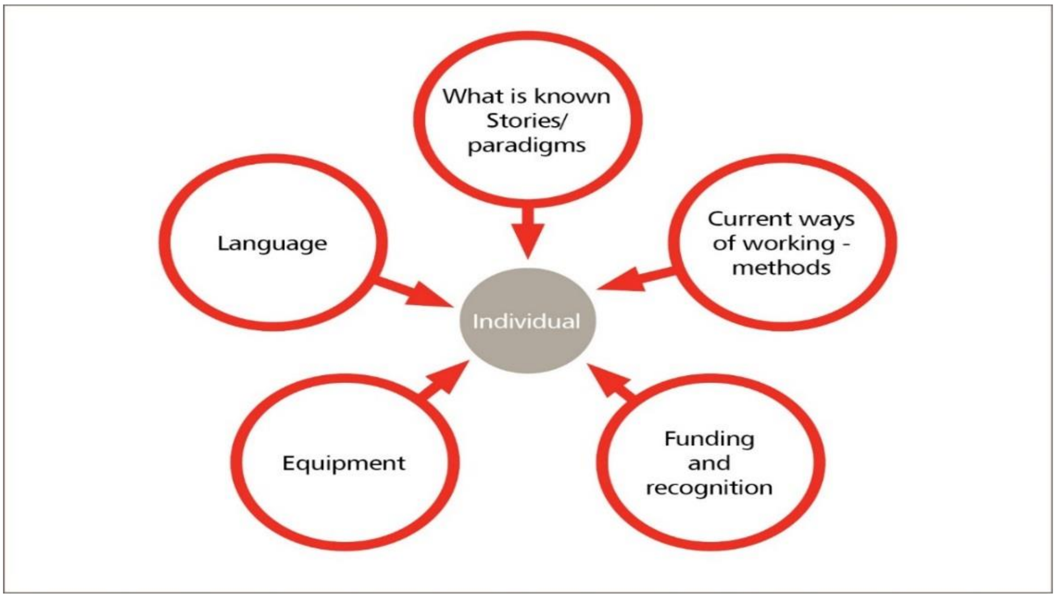

Figure 6: Aspects of the social ways of working

In science, technology and equipment has played an important role in the creation of knowledge - even the simple microscope had a long-lasting impact upon scientific knowledge creation. In Galileo's time the telescope enabled a greater range of data to be accessible, but if humans had evolved more slowly or Galileo had not recorded his observations, the story that is now told about the universe would be different. Much of what was once observed can no longer be seen (Du Sautoy, 2016) and although the stars within the galaxy remain, the system outside is no longer visible. Technology is developing and without particle accelerators there might not have been a need for a story to explain 'quarks' or 'pentaquarks'.

Whilst the social factors and the role of others help to shape the creation of skills, facts or information, they are not the knowledge creation processes; information can be given to others, but it is not knowledge until accepted and used. The social settings influence the individual's SKC but the individual's personality, presuppositions and motivations play an important role. The strong programme (Bloor, 1983) would advise that society distorts the knowledge with macro-social influences such as social class (Barnes and Shapin, 1978), and this affects individuals' beliefs. The famous case studies from within scientific research facilities (Knorr-Cetina, 1981; Latour and Woolgar, 1979) focused on specific laboratories but found no evidence of these macro-social issues in their research. Similarly, not everyone with high economic capital will go on to have an interest in science (Kjærnsli and Lie, 2011): life is not so predictable.

4.3.6 Current Public Policy and society

Whilst the community at large impacts on the SKC, there are also wider issues of influence. Recognition affects what society is interested in funding, in addition to influencing professional viewpoints. This is part of society, but it is also influenced by the public policy of the time. The phlogiston theory is an historical example of such influence. The theory was held for more than one hundred years and stated that burning objects released a fire like substance called phlogiston, evidenced by the flames seen as the phlogiston escaped. Priestley, a famous scientist of the 1700s, had confidence in this theory, and was far more influential than Lavoisier who suggested that a gas was responsible. Priestley and Lavoisier both discovered oxygen, although they did not realise it at the time. Priestley never accepted that phlogiston did not exist and held onto this theory until his death (Hoyningen-Huene, 2008).

Some facts, and theories that are developed may not be used - for example, currently string theory is not the mainstream of quantum physics**.** Knowledge can be influenced by power and money, as demonstrated by the story of Dolomite (a type of limestone), that was discovered by Deodat de Dolomieu, in 1791. Yet it was previously discovered by Giovanni Arduino who correctly identified its composition and formation, but history only remembers Dolomieu because he had cultural capital (Hacking, 1983).

Public policy does not only influence the acceptance of knowledge but also the attainment of professional status. Certain types of learning and key skills become valued above others and what is valued often maintains the status quo (Bourdieu, 1990). The 'interest problem' (Longino, 2002), is an example of this wider influence, where scientific research follows only the money and power, finding cures for affluent societal problems at the expense of the problems that beset people in less affluent parts of the world. This approach differs markedly from the view of the sciences expressed by the successful science educators in this study – science as the saviour of the whole world. The published view of the objectivity of scientists represented in textbooks promotes an interpretation of scientific knowledge as monistic. These text books are written for educational purposes and encourage non-scientists to embrace 'an ideological doctrine of disembodied scientific objectivity' (Harraway, 1988, p.576). There is little evidence for monism in the sciences, but monism makes the divide between the social and rational view of science more comprehensible.

Knowledge creation is a complex process involving the selection of techniques, problems, and equipment, with scientists working together and where each situation is different. The rationalist view of knowledge does not question the status of the sciences, and such reasoning and rationality has occupied an influential position in the field of education. For the facts, skills and information to become that which is shared in public, the contextual factors are removed. An example is the peer review system of academic publication which emphasises some factors and redacts others and 'as reviewers are essentially the authors' competition' (Bence and Oppenheim, 2004, p.8). As a result, there is a relocation from creation to publication, often leading to simplification. This simplification might make the knowledge harder for those who are not encultured or assimilated in science to understand or accept. Whilst I accept the role of society in affecting the development of knowledge, I do not accept a postmodern approach to knowledge, where knowledge is relative to a cultural standpoint and are dependent on experience or subjectivities (Moore and Muller, 1999).

4.3.5 Summary

This chapter began by defining knowledge and the different ways in which it is used. The discussion began with why knowledge was important in this study and then a range of views were presented these included:

i. Knowledge can be a state, an activity, or a possession (Fabian, 2014 p.444) and the issue of knowledge and knowing and whether there can be knowledge without a knower (section 4.2) I identified that the core issue was about complexity and how science knowledge does not link to common sense observations;

ii. Two different models were suggested, both of which also related to the complexity argument. The ecological realist definition identifies the issues of the environment as being too complex and that observations are informed by theory (section 4.2.2). The evolutionary argument suggests that the way science is created and how the child develops their curiosity is linked to an evolutionary need for knowledge as part of survival and that science has been effective at solutions for the issues that threaten humans (section 4.3.);

iii. These definitions were used alongside the interviews and the case studies to begin to identify a model of knowledge creation. The model of vertical and horizontal discourses created by Bernstein was used as a starting point to understand the different types of knowledge, resulting in The Horizontal and Vertical structures of knowledge (HVSK) although there many differences between the Bernstein model and the one created with the addition of the social aspects of knowledge (section 4.3);

iv. The individual or small group, is influenced by the community within which they are located, creating unique facts, skills and information within the vertical specialised knowledge model. Knowledge creation starts with their distinctive contribution, their creative imagination, a new and different view of the world, or a variation on a current view. Some of their ideas might be accepted by the community but the community (and public policy) influences what is accepted and acceptable (Bohm and Peat, 2000). (Section 4.3.3);

v. It was accepted that knowledge creation is not free from history, social trajectories or context and monism can reduce the options further. Society influences and affects the decisions made by the individual/ group at the centre. All people use aspects of knowledge from the horizontal plane, although these everyday knowledge functions differ for each person they are informed and influenced by their biography (Section 4.3.3);

vi. Knowledge from the vertical structure can be changed, and previously specialist knowledge will become part of the public domain, perhaps via teaching or, in the case of the Higgs Boson, through the media. This process requires the translation of knowledge from the specialist language of its creation into a language suited to the new audiences. In some cases, new analogies will be used to make this knowledge more accessible, but the story of its creation and the people who were instrumental in its discovery are often included.

Knowledge construction is not a simple process, but its creation is important. The HVSK and SKC are composed of both the rational, social and psychological approaches. The social and rational divide is a reductionist approach that works within the bounds of current understanding but fails to address restrictions. It is not the human understanding nature, or humans creating nature, but instead humans, their views of themselves and their society are part of nature. Knowledge is communicated as narrative, with its agents and actions altered with the repeated telling, and the degree of inevitability increasing as it crosses the boundaries of space and time (Collins, 1985, p.144). When the knowledge is communicated it is as a simplified story and it becomes more certain and more dramatic (Fleck, 1935, 1979) than it was when it was first created. While there may be some aspects of knowledge common across a greater number of vertical structures, (represented as yellow blocks in Figure 3) and the way the knowledge is communicated within different domains could vary greatly.

The model presented here forms a framework for analysing the case studies of the science educators that follow.

Chapter 5: Methodology

> Studies of teachers and teaching reveal that many researchers are becoming more and more 'qualitative' in their craft. This is especially true where researchers are attempting to understand teachers' feelings, attitudes, and values and how these are infused in teacher knowledge and practice. (Gudmundsdottir, 2003, p.293)

5.1 Introduction

In undertaking this study, I selected an approach of which I had no previous experience. This, in hindsight, has made the process harder than using a more familiar mixed methods approach. Yet it has provided an opportunity for personal learning that would not have otherwise occurred. I have avoided the use of any quantitative analysis, whether that was counting the sentences that showed personal agency or more formal discourse analysis (Gee, 2011), not because those approaches have no place in auto/biographical work, but because the case studies on their own have a powerful resonance and provide rich and meaningful material (Bainbridge, 2015). This allowed new perspectives to be brought to the familiar and for personal learning to occur.

As indicated in section 0.4 Auto/biography has many forms and approaches and I decided that my approach would be to enable the participants to tell their stories and then to identify what was important to them. Science is a subject that is often alienating, and narratives provide an opportunity for wider understanding (White, 1981) so the life stories of these successful science educators help illuminate some of the issues. This chapter is in five sections and attempts to provide information on the processes used to examine the research questions (Section 0.3)

The first section details how I began to undertake this research alongside the need to learn new technical language, and new ways of working. It explains how I worked as an apprentice (Lortie 1975), learning the new rules and analysing the language used by all involved. It will detail how I gained an insight into how researchers use this method which allowed the familiar to be seen in an unfamiliar way. The second section discusses the practical aspects of the sample. The third section discusses ethical issues using the frame of integrity (MacFarlane, 2009). The fourth section examines the process of interviewing and the final section discusses the role of analysis and writing, which details the continued struggle with a scientific positivistic view of the world and my struggle to write in an auto/biographical way.

5.1.1 Undertaking the research

An individual's story has many influences and whilst an individual can tell stories to remember events, to entertain or even to mislead, groups tell stories to mobilise others as well as to develop a community (Bruner, 1996). Individuals in this thesis tell their own story of science education but also retell the dominant narratives of primary science education. I propose that these narratives are of the way the world is accepted to be for this group. Their personality and style (a category in the SKC described in Chapter 4), defined as the attitudes and patterns of the behaviour of science educators, play an important role. Their presuppositions and motivations about science influence how these science educators construct reality. Yet the primary science curriculum is bounded within the wider culture of schools and schooling, which is in turn affected by the expectations of the curriculum and the myth of how science works (Latour, 1979). The role of others to support and protect, challenge and disrupt also has an influence (CBI, 2015; Wellcome trust, 2017) as story production is never an isolated activity (Plummer, 2001). Significant 'others' shape the lives and modify the kind of person that emerges. Within this policy layer are macro elements - the values, rights and obligations of the science educators, alongside the opportunities and issues of power. Many of these macro issues have undergone repeated change through curriculum reform, assessment regimes and working practices or habitus (DfES, 1998, 2004; Bourdieu, 1990).

Moilanen (2002) suggests that auto/biographical research suits the complexity of teachers' work and the indeterminacy and richness of their experiences. Whilst Bruner (2006) suggests that the principal way in which realities are shaped is through the stories that are told, listened to, or read, Feldman (2005) advises that society also plays a major role in the creation of these stories. I posit that in order to understand a community, appreciating their stories is of vital importance, and these stories of science and science education take time to change.

All ideas are shaped by the methods and ways of communicating that are adopted within the culture, and together they create the character of this micro-culture; in this case, the micro-culture of primary science education. Ideas are interdependent and inseparable, they work together to create the narratives which underlie practice. In order to identify these micro-cultures, I selected auto/biographical methods that engaged with the lived experiences of the science educators enabling access to some of their thoughts. The process made me challenge what I understood and resulted in the creation of the SKC.

5.1.2 Choice of method

It is through the very process of telling the story that participants demonstrate their uniqueness and provide a vista on their perception of the world (Bochner, 1997). By attempting to capture an aspect of primary science education through the stories told by the successful science educators, who have influence on the curriculum and many different teachers, I began to understand the issues from a different point of view. Another reason for using this narrative approach is that teaching and learning, is 'messy' and is more than an achievement in planning and 'thoughtful pedagogical moves' (Colne, 2001, p.23). Colne suggests that teaching is a lived accomplishment that is related to experiences via the people and the patterns of teaching and learning acquired at an earlier time. Teaching is therefore a cultural activity that has both a feedback to the past and a feed forward to the future (Ibid).

Society is composed of many layered groups and individuals do not exist solely in one group and this influenced the formulation of the SKC (as discussed in Chapter 4). Primary science education could be identified as one of the vertical columns of specialised knowledge in the HVSK presented in Figure 2*.* It is alleged that knowledge can be hardened by outside constraints (Feldman, 2005, p.26). In primary science education, these outside constraints have been identified as 'confidence, external testing, inadequate space and resource' (Harlen, 2011, p.8), are well known and reported on (Black, 1995; Boyle and Bragg, 2006; Sharp et al., 2009). In section 2.4.1, I identified the methodology selected for examining the current paradigm of primary science. However, whilst confidence is an internal feature of teachers it only becomes an external constraint when it is linked to teachers' subject knowledge and pupil attitudes and ultimately with the leaking pipeline (Royal Society, 2010; CBI, 2015), (see section 2.6). I reflected on the literature whilst working with the transcripts as this process was an integral part of how I made sense of the biographies and what participants communicated about the narratives and ideas in primary science.

My initial thought was that through using an auto/biographical approach it might be possible to identify the interpretive systems (Feldman, 2005) of these successful science educators. As narratives allow the construction of identity and help individuals find their place in a culture (Bruner, 1996), it appeared that an auto/biographical approach might provide opportunities to examine belief systems and reasoning for action, particularly if undertaken in a collaborative way. As it was not possible to involve all science educators, a sample of nationally known and successful people was selected (See section 5.2.2 for a discussion of the method of selection). Researchers have contended that narratives are very powerful and have the potential to influence people's understandings and beliefs, and essentially promote a societal and cultural change (Schank and

Berman, 2002). Webster and Mertova (2007) demonstrated that narratives have educational value, as stories within teaching and learning contexts are generally intended to help learning. I pondered whether the stories of science that the educators would tell would in some way illuminate the factors that were important in their educational environment. These narrated stories of science educators' lives allowed the communication of their experiences and, as will be revealed, the resulting stories paint vivid pictures of belief systems, personal identities and interpretations of primary science.

I wondered if any of the aspects of the past, the present and the possible (Bruner, 1996, p.94) shaped the participants' stories. I wondered if a common model of thinking might be revealed which linked all the participants, something that Feldman (2005, p.29) identifies as the 'unitas multiplex'. Feldman suggested that these cultural instruments were a form of thinking or cognition which, in turn, become the models used by the group to describe their world (Feldman, 2005), and that these models were then altered by the group according to certain rules, set in a particular way. This approach has similarities with Mead (1934) who found that the individual is reliant on the group for their identity. Danielsson and Warrick (2014b) conversely found that within science teaching, identity was varied.

In listening to the stories of science, I discovered that there were unique aspects of each story, and this provided an insight not expected or anticipated. Yet there were also some similarities, and this resulted in the questioning of my understanding of knowledge and the creation of the SKC and the vertical and horizontal models of knowledge (as discussed in Chapter 4). Understanding how my thinking changed requires an understanding of the processes at work, beginning with being an apprentice in this very different field.

5.1.3 Working as an apprentice

Initially I planned to examine what Plummer termed 'short stories' (2000, p.26), and to generate a number of these life stories that together made one account of primary science. I decided upon six participants as Morse (1994) suggested this was an appropriate number to use (cited by Merrill and West, 2009, p 106). I had little understanding of the process at this time and thought less than six participants would be limiting, as my worldview was very much still bounded by science. I was not aiming to grasp the fullness of the person's life but to confront a specific issue, focusing upon their view of primary science teaching and their ideas of the nature of learning science. My starting point was to ask the participants for an account of science teaching without 'intimate familiarity' (Plummer, 2001, p.37), because deep down I had been indoctrinated into that way of working and therefore still held a view that research should be objective. This mind-independent objectivity (Husserl, 1970) of the external world is a defining feature of science, so I understand that my struggle was not unique and is inherent within the familiar debate of 'objectivity versus subjectivity' in research (Clough et al., 2006). I had not at this time thought about the cost of the research, that it might change my sense of identity and that the result might be 'liminality' (MacFarlane, 2009, p. 54), which described perfectly the sense of disorientation at the threshold of new and old ways of thinking - as I no longer had a science worldview but was not yet comfortable with a non-science perspective.

In order to learn about auto/biographical research, I engaged with interviews conducted by my supervisors, first watching a 'mock' interview of a participant, followed by an individual interview exchange with another supervisor where he first acted as the interviewer and then as the interviewee. Listening to the questions as well as the way he responded to statements, and then comparing this to the more direct questioning approach I had taken previously, was a learning experience. I had worried at the start that if there was no list of questions there would be silence. The reality of the situation was that the conversation seemed to flow unforced: 'A structured interview is a crutch: it pushes the researcher into a well-defined role' (Plummer 2001, p.142). Also, many standard interviews fail to address the meaning that the participants make, and what is said may be interpreted by the researcher afterwards in a very different way (Mishler, 1986). With the auto/biographical approach there was an opportunity to revisit something that had been said previously and to ask for more information which provided clarification. The open nature of the interviews enables the participants' views to be understood and articulated so their meaning is not lost.

I decided I should practice both the art of questioning and being the interviewee. A more experienced research graduate agreed to support this stage of my development. Being an apprentice was a worthwhile experience: it provided an opportunity to understand, from both perspectives, what the interview process felt like; it enabled questions to be discussed and aired; and it became apparent that such an approach only works if there is trust and if the interviewer is a good listener rather than one who wishes to relate all the experiences back to themselves. It was at this point that I decided, where possible, to aim for a co-researcher role with the participants, by involving them in the analysis of their stories and to meet with them on more than one occasion. I hoped this would help to identify if any lines of enquiry were forced or if my questions appeared to be leading. Letting participants use their own words and to explain ideas was supportive in ensuring that all involved understand words in the same way (Holloway and Jefferson, 1997).

I worked with an experienced biographical researcher to undertake a taped interview so that I could further examine questioning techniques. This provided the opportunity to reflect, as a participant, on different styles, approaches and to adapt and adopt these within this research. These approaches allowed access to a different methodological frame and to a group of researchers who were successfully using these approaches. One was working with professionals within the education sector, and this provided an opportunity to examine the role of auto/biographical research at greater depth. The participants involved in this research were very successful practitioners. This is not unique, as West (2001) undertook a study with general medical practitioners and Reid and West (2016) one with career guidance practitioners, suggesting this is a method which would be suited to teacher educators.

5.2 The process of biography

Here, the processes at work, and how the interviews allow for the possibility to make and remake meaning using a humanistic approach, will be examined. Whilst such research involves developing the relationship between the participants, it should be acknowledged that there are also unconscious processes at work (Roper, 2003). In all research the participants might tell a story that they think is wanted by the researcher (West, 2016), but involving the participants in the analysis provides for increasing reflexivity. I begin with how the participants were recruited and some key information about the process.

5.2.1 Recruiting the sample

As I began to question if science could be invented rather than discovered (Schizas et al., 2015), it became more acceptable to adopt an approach that recognised that there is no single reality that exists independent of interpretation, 'So that what happens in the particular' (Bainbridge and West, 2012, p.243) can be used to draw attention to the multiple meanings that are inherent in different understandings of primary science. In order to identify these, a range of participants was required. Those who were asked to participate needed to meet certain practical expectations as they needed to be 'key people who will have a central grasp of this cultural world' (Plummer, 2001, p.154). They also needed to be good story tellers and not just respondents (Holloway and Jefferson, 1997). Whilst one of my supervisors questioned if all people are not great story tellers, I think telling a story and narrating your life to a stranger are two different things. I decided to interview a sample of successful science educators, who had an influence on primary science at a national level. It was thought that this approach would result in participants who were thoroughly encultured and currently involved in primary science (Spradley, 1979).

There is a perennial issue over the selection of the sample and many studies do not define the parameters in any detail or explain the decisions taken by researchers (Schram, 2014). As a result of this criticism I decided clarity was vital. As all science educators are individuals and all individuals differ, there was never any belief that it would be possible to select a random sample, where every possible sample had a fixed probability of being chosen. It could be argued that the method selected was a type of expert sampling, or a form of purposive sampling of science educators, also called judgment sampling, based on the 'the deliberate choice of an informant due to the qualities the informant possesses' (Tongco, 2007, p.147).

However, as the numbers of science educators remained too large for a purposive sample technique, an opportunistic sample was selected using individuals who fitted the criteria that had been identified. I focused on national standing, gender and working in different educational settings. Each will be discussed in turn.

- National standing and working within the field for more than ten years.

Whilst the criteria of having more than a decade of experience could be viewed as arbitrary, it was selected to ensure all science educators had experienced more than just the previous curriculum (DfE, 2013; DfES, 2004), and some of the recent changes that have taken place in science education. In fact, the resultant group has worked within the field of primary education for more than twenty years. National standing required that those selected had presented workshops at the Association of Science Education conferences or similar during the previous decade and had published work within the area of primary science education. The publications could be peer-reviewed articles, teaching materials or policy papers. It was not possible to select people of whom I have no prior information about within this context, but I did not approach anyone whom I would view as a friend or work colleague.

- Sex

Although I selected an opportunistic sample, I wished to include responses from both male and female participants and therefore when one participant was selected, the next approached was of the opposite sex. This is not because of the limited number of women in science, but because Keller (1978) suggested that science itself is masculine (p.188). Also, I wished to have a view of science education that includes the whole population. Whilst gender was not the focus of this work, ensuring a sample representative of the population was important. The opportunistic sample did not result in participants from ethnic minorities or those with disabilities who are underrepresented in science and science education (Royal Society, 2014).

- Undertake work in different educational settings

The final criterion was that the educators should work in different settings, to include a wide range of experiences and influences that impact science education in the classroom. The different settings include employment as a Local Authority science advisor; working with postgraduate and qualified teachers in a university setting; employment with a professional body; and/or research into science education. I did, however, focus my requests on science educators who worked with teachers rather than those who were based in academic institutions, and I selected those who had influence on primary science policy and practice.

This was found to be a rather simplistic selection criterion as many of the science educators undertake a range of roles and, for example, even if they were based in the university sector it did not preclude them from acting as an adviser for government (Peter and Justine). However, it did ensure that the sample was diverse and that a range of settings was included. In order to collect this opportunistic sample, I did not attend any events that I would not have usually attended, and whilst this could be a disadvantage, it meant whilst it was purposive it was still opportunistic in nature.

5.2.2. The opportunistic sample in practice

I thought it would be difficult to encourage people to participate; in fact, the opposite was true. If I happened to meet someone who fulfilled my criteria, I asked them if they would take part in the research; all those approached agreed. The opportunistic sample was effective as the goal was not to produce data that can be generalised to larger populations, but rather to explore the range of attitudes, values, and beliefs that are held, and the strength of feeling and reasons underpinning these.

All personal requests were followed by phone calls and/or emails and the sharing of the outline and ethical considerations of the research. This allowed, in theory, opportunity for those who took part to have a fuller understanding of the process and to have time to change their mind. Locations and times were selected to suit the participants. Sometimes, this meant considerable journeys to their places of work or, at the participants' request; one initial interview was undertaken at a conference in a breakout room after sessions had finished for the day. All interviews were recorded and then transcribed verbatim without any punctuation because I did not want to edit the transcripts. Peter and Justine both added punctuation when they returned their shared transcripts and for some participants follow up interviews were arranged.

5.2.3. Limitations

One of the limitations was after the first interview there were differences in the next steps. Some participants took a very personal approach to the transcript and editing it, sometimes by changing it and in one case by adding additional information to 'inform the reader'. By taking such ownership of the process participants impacted on the research in ways which were not planned. There needs to be an examination of the intentions and accountability of all concerned, although I would not go as far as Maclure (1993) who suggested such an approach is not about sharing a sacred text that is a contemplative, authoritative version free from biases but instead is more like sharing a mundane and pragmatic version. However, this is not a failure of the life story because, if stories, and accounts more generally, are understood for the ways in which they explain, justify and make sense of the raw data of experience, then the stories that we tell of ourselves and our doings are of no small interest for what they reveal about what we take and make ourselves to be (Maclure, 1993, p.377).

The making of self and personal reality was clear in the case studies, but it is not a conscious thing although it structures all experiences (Epstein, 1984). Participants were selective; the narratives are emotional, and the stories reveal aspects of the participants' beliefs. This selectiveness is not unique to auto/biographical researches, as even in responding to questionnaires, participants can answer in any way they wish. All elements of the narration contain information believed by these successful science educators to be significant.

Another limitation when researching within a familiar area is an inbuilt tension between a need to have certain understanding of the primary science landscape and possible inbuilt prejudices. For example, even the way the initial questions were formulated was as a direct result of a deep professional engagement with the experiences of teachers in primary schools and a personal engagement in science education. When examining my focus and reflecting upon my actions it was clear that whilst I had been interested in finding out about the educators' view of what would be lost if science was not taught in a primary curriculum, this was because of my ingrained belief that primary science was a central part of children's lives. I wanted to know about their perceptions of good science teaching, because at the time I had a clear idea of what I thought it should be and thought they might confirm my views. Fortunately, the participants were natural narrators, so these questions became rather irrelevant; they related instead what was important to them.

Plummer suggested that the ideal participants should be 'articulate but not analytical' (2001, p.136), presumably in case they might spin a tale and out-think the researcher. The participants in this study proved to be both analytical and reflective and instead of being a negative component this enabled them to be very supportive in the analysis stage. Whilst all participants were capable of diverting the research, this would have been the case in any research methodology, and even if the participants had reservations about disclosing personal information, they told stories that had internal consistency. Peter was the most analytical and was also the clearest in how he wanted his story to be told. I followed up the interview stage by asking each participant to reflect upon the process of being asked to participate. I found that all who agreed to take part expressed a certain pleasure in being asked.

5.3. Ethical issues

The ethical issues and concerns are outlined and demonstrate clearly how undertaking research in a new field results in the need to be mindful but was also empowering. As West put it ‘we need to be mindful of boundaries and limitations, in addition to the potential illuminative power of what we do’ (West 2016, p. 42). The participants telling their story was just the start, as Clough indicated:

> The portrayal of lives through life story research could be said to have three elements: the telling of events, the creation of text, and the interpretation of those events. (2004, p.108)

The interpretation of the transcripts and the creation of the texts took far longer than I had anticipated, and even towards the end I required further clarification from some of the participants. All these actions involve ethical considerations of confidentiality and informed consent which need to be addressed.

5.3.1. Confidentiality

The ethical issues related to auto/biographical-based research are many. I offered confidentiality and anonymity to all participants; however, some participants felt their story was so unique that anyone who knew them would know it was them. Others were candid about all aspects of their scientific life and then as a result wished to remain anonymous. All participants have been given pseudonyms. I agree with West that qualitative researchers must question their narcissism and agonise over whether it is appropriate to tell a part of a story (West, 2016). I also believe that Macfarlane (2009) is correct that research is about passion and curiosity and it is important to be aware of emotions: but this is a challenge for someone who had previously undertaken scientific research where emotions were removed.

Some participants told captivating stories, but in doing so provided information about their identity that simple name changes would not mask. At the same time, I was trying to come to terms with participants who argued against anonymity. The conflict as to whether redaction was required, or was appropriate, was challenging. One participant (Ben), as the process proceeded, became more apprehensive about the possibility of being identified and whilst content that the telling was accurate, did not want colleagues to be able to identify him or for his opinions to be attributed back to himself. I therefore removed all the identifying features and the sections of interviews as requested.

It was necessary to check and re-check, as the process continued, whether the participants wished to be part of this research process. I found the empty rhetoric of ethics (MacFarlane, 2009) was not always appropriate; one participant was keen to support initially, but then her life changed. She had checked and agreed the transcript and even answered some follow-up questions by phone and email, but then became un-contactable, and as a result this biographical material was not used. There were other elements of difficulty, such as sharing material that focused on some participant's naïve approaches to science (Schizas et al., 2015) or a viewpoint that science was only for the few. All these issues had to be considered in light of future harm. Talking to one of the participants in a second interview, a question arose about their view of science and the notion that science might not be objective; it was met with the one-word response, 'Bollocks'! As the process went on it became more and more apparent that the very process of writing about the participants' lives could expose them to risk (Josselson, 1996), but as West (2016, p.41) argues, 'we can strive to make material anonymous but … this can never be fully assured'. I adopted Macfarlane's (2009) stance that ethics is about the character of the researcher rather than a depersonalised ethical principle. The decision taken was to try to protect participants, even if this meant editing an element of their story, but at the same time to try not to conceal aspects which might prevent teachers in the future having a better understanding. However, making that decision, deleting part of the transcript, and knowing it was the correct thing to do, was challenging (Macfarlane, 2009).

All the participants were provided with the details of the research and asked for informed consent. In hindsight I am not sure that any of those taking part, with the exception perhaps of Peter, had full understanding of what they were consenting to, despite providing them with a script with details of the study and how their words might be used. The script included information on ethical clearance that follows university procedures, and the participants signed to say they gave their consent to participating in the study. Josselson (1996, p. xiii) identified this dilemma by suggesting that 'informed consent is a bit of an oxymoron given that participants at the outset can only have the vaguest idea of what they might be consenting to'.

In one second interview it appeared that the stories were in a constant state of becoming and that events that happened decades ago continued to shape a person's life. By re-living and re-telling aspects of their lives the participants could be asked to go back to times and places they might not wish to revisit. For example, Stephanie's identifying that she was a failed medic and the reference to it was like medical school again. As ethics is 'more than just not doing harm' (Merrill and West, 2009, p.168) it is important not to be overly intrusive in the lives of the participants. What I had not really understood when I began this process was that the past is a 'provisional construct, mediated through the present, including the workings of language and relationship' (Merrill and West, 2009, p.163). Having a principle of ethics is not enough, because deductive disclosure was always a possibility. Although all the participants are educated professionals and their consent might be considered to be informed, that does not mean they should not be given the ethics of care (Macfarlane, 2009).

Taking such an interpretative approach enabled a perspective that valued each unique individual, which I felt was previously missing from much of the published research in primary science where generalisations about teachers were made. This interpretative approach is predicated on an understanding that there may be multiple interpretations of events and situations (Josselson, 1996). I came to understand that the reality of science education is very personal to the individual participant. In order to access their reality, I had to 'get inside the person and to understand from within' (Cohen, Manion and Morrison, 2011, p.17), rather than from the perspective of my own reality. However, this is easier to write than to achieve as there is no observer-free approach and the account is never independent of the researcher (Denzin and Lincoln, 1994). It also was problematic as I found my writing disability became a major hurdle (see section 1.1.1).

5.3.2 Private thoughts becoming public

My positivistic science background was still exerting a strong pull and I was challenged by the tension between reliability and validity. These concepts are part of the positivist tradition, with Rolfe (2006) suggesting that validity is achieved through consensus on each individual study achieved by myself and the participant rather than by the blanket application of predetermined criteria. Andell-Stanberry (2017) stated that reliability is not a useful measure of quality in qualitative research and instead validity or trustworthiness, should be the aim. The positivist notion that validity can be achieved by the rigorous application of method or technique is not a guarantee of quality (Mishler, 1990). As the process of interviewing began, this worry faded as the depth of detail and the rich data of the individual stories provided an understanding of primary science from the perspectives of those who participated. It supported the assertion made by Reid and West (2016) that small samples offer rich understandings of breadth and depth of experience and perspectives within a field. However, in writing up the interviews and interpreting the transcripts I was aware that I was making the private thoughts of the individuals public.

Justine talked without a break for more than an hour and a half in her first interview and discussed many different aspects of science education, her presuppositions, and her ideals. After sending her the transcript, Justine made some alterations to it including the removal of whole sections. When asking advice about what I should do I was told I could discuss generally what was removed. I have not done so, not because of cowardice (MacFarlane, 2009), but because I believe that the right to withdraw means just that. This issue of who controls the narrative was not on my radar until after I shared the first transcript with the participant. It became more apparent when the challenge of a 'good story', the interpretation of the researcher, and the real meaning of the participants that had resulted from such an open agenda emerged. The openness allowed for both discussion of development and change rather than repression of stories (Mischler, 1986) but it also required discussion, clarification and the participants' support with the interpretation. I identified with Gibbs, (2007, p.97) who suggested that 'the depth of the commentary that accompanies the interview text is a challenge between ensuring the voice of the participant is heard and not taking away their story with an interpretive commentary'.

5.4. Process of interviewing

The process of interviewing will be discussed, including how I tried to gain an understanding of the participants' views of science, what their view of effective science teaching was, and what they viewed as important in primary science education. These good stories are defined by Merrill and West as 'rich in detail but also experientially inclusive and reflexive in character' (2009, p.113). Some of the issues with interviewing are shared alongside the motivations of those who took part, starting with the theoretical issues of biographical interviewing.

5.4.1 A Biographical interview

I undertook Auto/biographical work, with the slash (/) between auto and biography there to remind the reader that any biographical writing is always facilitated through the biography of the person who interprets, analyses and re- presents them (Stanley, 1992). There is a relationship between the autobiography and the construction of a life in biography (Merrill and West, 2009). As indicated previously (Chapter 2 and 4), narratives are the way in which reality is constructed and provide an opportunity to examine what I termed the paradigm of primary science from a different starting point. These biographical interviews were a creative space for me and the participants to share understanding (Merrill and West, 2009). The process began with one interview where interesting features were raised: ‘frequencies are rarely important in qualitative research, as one occurrence of the data is potentially as useful as many, in understanding the process behind a topic’ (Mason, 2010, p. 1). However, at the start I was unsure about how my involvement would, or could, alter the outcomes. My strength was my understanding of the wider context of primary science education and that I inhabited the same world as those I was interviewing. All interviews began in the same way with an explanation of the nature of the research and the focus upon primary science education, ensuring the participants were clear about the ethical considerations and signing the consent forms. I had selected three open questions to frame the interview:

1. How did you end up where you are now? (Their life story of science education)

2. What is important about primary science? (Their view of the nature of science)

3. What would be missing if there was no science in the primary school? (Their understanding of the importance of primary science)

In some cases, not all three questions were asked, and others were added if clarification was needed, but as I thought that those that have power in a conversation talk most (Edwards, 1980), I endeavoured to keep my role as an interested listener in line with my apprenticeship training. The participants were all successful people who needed little, or, in most cases, no prompting. In addition to taping and fully transcribing all the interviews I also kept field notes and diary materials. The interview process was very open, allowing participants to ‘choose the events that matter to them and put their own construction on them’ (Ochberg, 1996, p.97). The process did not feel at all contrived and I agree with Miller (1996) that such an interview allows people to explore themselves, their own beliefs and to be understood, but only if that is what they wished.

After looking at a fellow researcher’s transcript, it became very clear that I let the participants do the talking, intervening very rarely. At times I wondered if this meant that I missed things. Examining the transcripts raised some questions but as I had decided, where possible, to interview the same people more than once, these aspects were followed up within the subsequent interviews. I wanted to be an observer and an interviewer, not ‘a manipulator and quantifier’ (Apter, 1996, p.30). I was aware that in listening to their stories there were elements that were mirrored in my own, and their memories and understanding were sometimes very familiar.

I wondered initially if the first question concerning their professional story was clear enough. It allowed participants to start from a time of their choosing: one participant started their first words as a toddler, two with teacher training or why they wished to be a teacher, and one began their story as a secondary aged pupil. Only Justine began with her degree subject and life as an undergraduate. I followed the life story question with the questions identified above. My scientific grounding was still present in choices that I made and as a researcher I was lucky to have a group of excellent raconteurs so that the processes were effective and the stories that were shared were detailed. Analysis was not simple.

5.5. The Analysis processes

I acknowledge that I have played an active role in determining the relevant points in each of the stories narrated in this work, as well as the perspective from which the story should be told. I have not undertaken this task unaided and will detail how the transcripts finally became the chapters in this thesis. For some participants there have been multiple meetings over several years which has resulted in participants' active engagement in this writing process.

5.5.1 Transcription

The interviews provided qualitative material comprised of words, and how these words are said, and what words are used or not used, informs the listener (Gee, 2011). Initially I chose to examine the text from a linguistic stance, placing in bold all words that were emphasised (On the tapes these were clearly louder). Pauses were denoted by '..', with the number of '.' used to denote the length of the pause; 'ums', or other noises are also included. It became clear that I used this approach because analysing and representing the texts in such a way felt comfortable and postponed acceptance that this process would require writing skills I lacked. As West (2016) argued the process requires the researcher to bring narrative coherence to the work. In the end I worked with the whole texts and content, placing punctuation to enable easier reading and examining the meaning of the whole, not the parts, with the help of the participants.

The behaviour of the participants with their transcripts was as diverse as the participants themselves. Stephanie narrated her story in different voices and at times acted as a narrator. When the transcripts were returned, some participants changed the text whilst others just added punctuation. Peter was very thorough and returned the script after six months with the following notation:

> I attach herewith an annotated version of the interview transcript which you sent me. I have inserted amendments or clarifications in italics, usually in brackets, and also inserted hyphens to render my comments more clear by breaking up the flow into specific sections. (Peter, by email)

Sending the transcripts back for checking exposed other outcomes – some have said the transcript was fine, making few changes and responding very quickly; two made several edits to their transcript, not for accuracy purposes but to remove small sections. Another was keen to add material into the script to enable a better understanding of what had been said. I acknowledge that I have brought my ‘own culture, norms, values to bear in conducting, analysing, interpreting and reporting’ (Cohen et al., 2011, p.575), as have the participants.

In the next stage, interpreting the words and making sense of them was personally problematic, and this concern was succinctly identified by Josselson when she discussed her own participants and noted that ‘Lydia merely agreed to talk to me. She never agreed to subject herself to my interpretations of her life’ (1996, p.67). However, the alternative is just to produce the transcript with no changes at all.

5.5.2. Trying to make sense of the material

All participants’ stories became the research material, checked and rechecked, and the analysis was the start of the process to create some kind of sense. I listened to the tapes and immersed myself in the recordings. I did not use traditional coding but initially used the pro forma recommended by West in order to ‘understand the overall form’ (Merrill and West, 2009, pp.136-7). The proforma was a starting point to consider key issues and to enable themes to be identified alongside a thumbnail sketch of each participant. I found working with the transcripts a challenging and detailed activity and one that is harder than any quantitative research I have undertaken previously. As a result, I can identify the changes that had taken place in my understanding of knowledge and that by this point I accepted that human life can be looked at simultaneously from both within and without (Nagel, 1986). As a result of examining the transcripts and talking to the participants I found myself challenging what I knew about the sciences, what I knew about knowledge and how narratives were linked to both these areas. I used academic literature to try and understand my own presuppositions and to examine ideas in the transcripts and found that what I was learning was challenging my understanding of the sciences and science education. In Auto/biographical terms this is termed reflexivity; in real life it is uncomfortable but liberating.

I initially shared transcripts with fellow researchers who used the West (2009) pro forma in their own work. Through this sharing process, I identified that each participant discussed their presuppositions, their social ways of working and the policy that influenced their working lives and in turn this helped to build a ‘comparative and questioning dimension’ (Merrill and West, 2009, p.140) and a sense of substantiation. It was also the fundamental step that resulted in the development of the SKC model.

It is worth reiterating at this point that I began to acknowledge that these stories were re-interpretations, for '[s]tories live on in the present — shaping the teller's experience. In this way, the teller has begun to construct a present reality out of past events' (Reid and West, 2016, p.176). I was enthralled by the stories told – I became immersed in what they meant, what they implied. I became so involved that I forgot they were someone's life and did not always evaluate whether I was being careful enough. It was helpful to know I was not alone, reading More's account of her analysis of her participants: 'Usually this has made my own voice too dominant and there has been the temptation to be judgemental and dogmatic' (2004, p.65). As I was changing my stance, I found myself questioning views I had previously held, and then questioning why and how my understanding had changed. As I worked with the participants and as my epistemology altered, I re-interviewed the participants and began to develop the model within their biographies, trying out different ways to capture the participants' essential elements.

I worked with a single interview at a time, although I did not start to analyse any interviews until I had carried out three complete interviews. This was in part because I told myself I did not want to focus on themes before I had heard several stories, a throwback of positivistic thinking. This delay in starting the analysis process has meant I have spent most of the research time playing catch-up (Silverman, 2006, cited by Merrill and West, 2009) but looking back it also allowed me to focus on the aspects I enjoyed most (reading) and avoiding the written aspects. I found, even with the help of the participants, it was difficult to know how to represent the person's life and then found it almost impossible to tell their stories in engaging ways. I understood the need to remove the remote and authoritarian voice but have struggled throughout in the creation of a valid text. Ben (Chapter 6) and Justine (Chapter 8) were the most challenging because their views were very different from each other and my own, but these problems made me question my beliefs and were fundamental to the creation of the SKC.

5.5.3. The role of analysis

I returned to the participants themselves. I also revisited the story approach of Bruner and engaged with the question of knowledge. This was one of the hardest parts of this learning process - there was no computer programme to shift the data, only the participants' and my own developing understanding of epistemology to guide the process. Bruner's suggestion that the 'grand theories of science are more story-like than we had expected' (1996, p.122) had initially triggered my interest in narratives. As I struggled with making sense of more than 100,000 words of transcripts, I returned to Bruner and his suggestion that the collective narrative gives science its strength, making it a 'good group', and providing a 'community's collective experiences, embodied in its belief system and represents the collective's symbolically constructed shared identity' (Bruner, 1990, p.76).

Burke proposed that language is not a tool that creates reality but instead is always addressed to the audience (Burke, 1966). The participants could have selected different fragments or events to narrate the story of their life to different audiences. Their audience was another science educator. The stories that they told have agency, and to accept them in any other way is a case of naive verbal realism (Burke, 1966). I thought Burke's pentad might provide a way of examining: what was done (the act); when and where (the scene); what the agent did (action); why this was done (agency); and for what purpose (goal). The issue was that some accounts contained many short stories, and some had missing scenes. It was helpful process because the more I worked with the narrative structure, the more I questioned my own beliefs, which resulted in changes to the SKC. As discussed in Chapter 4, I came to understand that by linking the participants' presuppositions and motivations with their biography and personal style new insights were generated. Their stories were all set within the culture or social setting of primary science and were influenced by colleagues and others to differing amounts. The events in their biographies were also influenced by public policy, the influence of the wider society of science (government, professional institutions and research) so I therefore re-examined each of the successful science educators' life stories using the SKC (Figure 4)

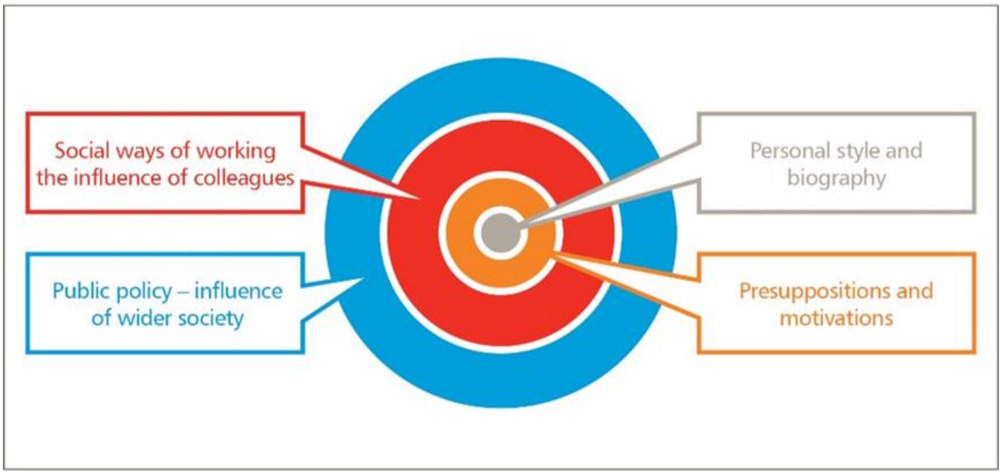

Figure 4: The sphere of knowledge creation

The stories told by the successful educators focused upon their inner world and how they interpreted the nature of science and primary science. The way participants built their horizontal and vertical structures of knowledge (HVSK, see figure 3) resulted directly from their individual SKC and as a result each story was unique. The HVSK presents the participant's knowledge base but is referred to less in the analysis of the case studies because the case studies narrated their knowledge creation (SKC) more explicitly than matters that relate to the knowledge classification or HVSK model. The HVSK does feature subtly in the biographies as the participants' understanding and presuppositions are linked, and Vision I and II science views (introduced in section 3.5.2) a dominant narrative in science education (or gaze) was present in many of the biographies. In Chapter 10 where the primary science gaze is discussed some of these issues are revisited.

When the biographies were analysed, different aspects of the SKC had greater importance for each participant at different times within their narration. Initially the chapters were written to reflect this difference for example Justine's biography began with the influence of public policy because this has a greater influence on her in the first interview because she was working at that time with government. Starting from different parts of the SKC model made the structure of the chapters more difficult for a reader and, acting on advice, I changed this, so each biographical chapter begins with personal style and biography, as this also sets the scene for the reader, who then follows each chapter systematically from the centre to the outer rings of the SKC.

5.5.4. Communicating findings

I decided to position each life story as a separate chapter because primary science has a history of simplification. As the concept of the gestalt demonstrates that the whole is more than the parts, I chose not to simplify the complexity by amalgamating the biographies. The life stories I share here are those of the participants in their words. The key aspects of their stories were selected by the participants, which means there are several issues that are included which, might not have included if I had not selected a co-authoring approach. This might make the process harder for the reader but maintains the complexity of primary science education. In order to avoid creating iconographies of 'teacherhood' (Maclure, 1993, p.382), complete sections were included in order to retain the complexity of the participants' versions. Nonetheless, as West identified, '[t]he texts are open to further interpretation and the stories are never complete' (1996, p.13).

5.5.5 Summary

In this chapter I have discussed the challenges of an auto/biographical research position for a positivistic researcher more used to mixed methods of research. I have identified that auto/biographical research has several benefits and this chapter has covered several areas of research methodology:

i. Auto/biographical research suits the complexity of teachers' work and the indeterminacy and richness of their experiences Moilanen (2002) that teaching is a cultural activity that has both a feedback to the past and a feed forward to the future (Colne. 2001) (section 5.1.). In discussing the choice of method, I indicated that the literature search (discussed previously in section 2.4.1) played a part in the methodology. It is only referenced here and not included in the main methodological discussion because my understanding of what auto/biographical should contain;

ii. I had little understanding of the process of auto/biographical work and there is a considerable amount of detail about process in this chapter: from being an apprentice; how the sample was selected; why I was still concerned with validity and reliability; and defining the term successful science educators as, 'key people who will have a central grasp of this cultural world' (Plummer, 2001, p.154), related to national standing, sex and different educational settings (section 5.2);

iii. The ethical considerations were discussed using the ideas of MacFarlane (2009) and the idea of integrity. Whilst integrity is important in all aspects of research, it seemed particularly important when the methodology is so intimately involved in peoples' living life (section 5.3);

iv. The definition of auto/biographical work was discussed later in the chapter and how this approach fitted with my developing understanding of narratives in science. As a new researcher, I leant heavily on other more experienced colleagues for support with transcripts and interviewing (section 5.4);

v. In the final section, the decisions that were taken on how to work with participants and their life stories were outlined.

It was acknowledged that some elements of methodology have been introduced in Chapter 2 when the confidence and subject knowledge dominant narrative, called the paradigm of primary science, was examined. Listening to and discussing ideas with successful science educators led to my need to understand knowledge and science, which resulted in the creation of HVSK and the SKC models previously introduced in Chapter 4. I also discussed how elements of the literature that had previously been introduced in Chapters 2 and 3 came from the participants' life stories and that these life stories were the reasons for the examination of literature in Chapters 2 and 3. Having set the scene for the biographical chapters which influenced all that has been previously read, the action will now switch to the lived lives of the participants upon which this study is based.

Chapter 6: Ben - Science for some children

6.1. Introduction to Ben

Ben is an eloquent orator who holds a national role in science education. He started his career as a secondary school teacher and then changed to teach in a primary school. Although Ben now works principally with national organisations, he is a regular presenter at conferences and training sessions within the UK and has delivered sessions at America's National Science Teachers Association (NSTA) conferences. Ben's current role, working for a science professional body, ensures his views are listened to and he influences the work of many primary school practitioners. In addition, Ben spends a great deal of his time in classrooms watching science teaching and evaluating lessons.

The analysis of Ben's story has taken place over a four-year period, starting with the initial interview at a science conference. He has taken an active role in explaining his story, selecting the things that should be used and items that needed amending. Ben worried that some of his comments could reflect badly upon him and therefore many aspects of his story have been anonymised and shortened. The gestalt (West, 2016) in this biographical chapter is the contradiction between the role of fun science lessons and Ben's view of the complexity of science, leading to an ambiguity about the relative importance of fun and complexity in the role of primary science. Ben's biography reveals the intricacy of primary science and reinforces the idea that teaching is not a script or a set of routines (Loughran, 2013). Ben has conflicting views about the role of subject knowledge in primary science, and what is needed for someone to be a successful primary science practitioner. Many of Ben's early thoughts and reflections demonstrate the conventionalizing efforts (Bruner, 2012) of the primary science literature, and the dominant narrative of primary science is initially accepted**.**

At the time of the first interview, Ben had just accepted a head teacher position in a primary school. Previously he worked full time as an independent science consultant; he found consultancy hard financially and was, 'just about making it work when I was offered this leadership role'. This role 'was the dream' which met his childhood desires of being a headteacher and running a school; furthermore, he considered that if he did not accept the headship, he would always wonder. Although he enjoyed being back in the school environment, mundane elements of the role became an irritant, especially those that took him away from teaching and learning. In the second interview, two years later, Ben had accepted a science role and he viewed this opportunity as changing him and the type of person he is:

> 'I get quite excited about opportunities so I kind of **jumped** at things and this gave me the chance to do other things which I suppose changed the person I was. It was not just about

> being in the classroom, it was about how many more people can I work with and get excited about science with.'

Ben now gets excited about science by working with teachers across the whole of the UK. He influences national primary science groups and, through conferences, thousands of teachers each year. I examined Ben's life through several interviews, I present the information for Ben using the SKC introduced in Chapter 4, (figure 4) with the subheadings colour coded for clarity.

6. 2 Biography: wanting to be a teacher

Ben always knew that he would be a teacher, saying 'teaching is in my blood.' I wondered if he came from a family of teachers, but he responded that 'as a very small child, I knew that I would be a teacher and had no interest in considering any other profession'. Ben was the first generation of his family to attend either a grammar school or university. He was not sure of the subject he wished to teach, stating 'over the years, what I would teach and to whom has varied'. In the first interview he explained this by saying: 'I was going to be a maths teacher because that was my best subject in school and then I was going to be a physics teacher because that was the subject, I enjoyed most, most of the time'.

Ben explained that he went to study for a degree in a subject, as opposed to undertaking an education degree course, as 'a subject is useful':

> So, every time I said I want to be a teacher, they said go and do a subject because you will have something to fall back on. The teachers in school said I could not be a primary school teacher because that was not considered to be a worthy profession for somebody who was considered to be reasonably intelligent. I ended up doing a subject for a degree which was Physics.

Ben undertook a subject degree because the teachers, whom he deemed credible, convinced him. His ambition, or aim, was to be a physics teacher, yet things did not go as expected. He spoke of: 'the [physics] degree which I hated, loathed with everything that I had and the only thing that kept me doing it was because I wanted to be a teacher'. There were bursaries to encourage more people to train as secondary physics teachers and Ben was persuaded to switch to an education course mid-way through his degree programme, 'although it did not take any persuasion in my part. So, I became a secondary physics teacher'. After a very successful teaching course Ben qualified and began his career - he has always used the term career to discuss his teaching roles. When asked why he became a teacher, Ben said: 'I wanted to find ways to engage others, to make that experience exciting for them. In a way, it is a hard question to answer because I have an innate sense of this being what I both want to do and should do'.

Although Ben knew he wanted to be a teacher he had mixed feelings about his first teaching position and narrates his experiences of working in a school where he did not fit because the ethos did not work for him. In a later interview he returned to this time and suggested his lessons might have turned pupils away from science; then, recalling some of the better lessons, was again unsure. I have included this piece as Ben's background as a physics teacher plays a pivotal role in his view of science and science education. The story begins with his first school after training:

> 'I went into school ... started on that career in a mixed, fairly low standard, secondary modern school. I went into this school, there was no A Levels to teach, there were a lot of disaffected children and I struggled actually to be honest with you, did not really love the teaching, did not really like the ethos of the school'.

When training to become a physics teacher 'every day was an adventure'. However, in his first teaching post, the day-to-day teaching of science in a secondary school with low standards of attainment did not live up to this ideal of an adventure, nor was there an excitement to his teaching. Ben considered leaving but did not want to give up on his childhood dream. He changed schools and later took the opportunity to change phases when he realised that primary was really where he wanted to teach:

> Thought I want to be a primary school teacher so started to look for a job but could not get a job ….every time a job came up that I thought I might apply for, nobody would look at me because I was a secondary school teacher with a degree in Physics with no experience of primary school teaching.

Ben identifies that as a secondary physics teacher with no primary experience he had no currency in primary, but eventually he managed to find a role within a small school:

> One day I saw an advert for a Key Stage 1 teacher in a local school, so I thought I would just give it a go and um they said we will have a trial lesson teaching and see what I could do. They were really nice about me and said we like you but we think you would be better off with older children … Six weeks later they rang me up and said 'now we have something for you, we have a Year 6 post - so that is close to Year 7 isn't it and how do you fancy teaching all of the science for Key Stage 2?'

Ben did not find it easy to be a teacher in a primary school, but he enjoyed working with the children. He felt the challenge was a lack of pedagogical knowledge of primary teaching. Ben's suggests his beliefs about the differences between teaching primary and secondary science and how primary science is about answering children's questions were developed at this time.

6.2.1 Presuppositions: Child centred teaching.

Ben loved being in a primary school and he developed his approach to effective teaching by using what Alexander would call a 'pragmatic, what works for me approach' (1992, p.9). He expanded his repertoire to include more ‘student-centeredness’ approaches (Oliveira, 2010, p.422) including an increasing awareness of the importance of questioning, and how his questions led to child-centred approaches.

> It took me a few years, to kind of work through; I just kind of got the measure of what they could achieve and how I could push them on. The children automatically generating questions, all the time and we would set up things to find the answers to their questions.

Adopting the children’s own questions as a teaching approach can be justified on curriculum, pedagogical, philosophical, and psychological grounds (Biddulph, 1990). Shulman (1987) contends that teachers draw their ideas of effective teaching from their own knowledge base, a base that includes: knowledge of classroom management; understanding of how pupils learn; what topics they should teach; how to teach these; and knowing what curriculum materials are available. Together these aspects form Procedural Concept Knowledge (PCK) which Ben developed alongside his didactic and instrumental (resource) educational capital (Vladut *et al.*, 2015). It could also be argued that he was changing as a result of the biographical processes; that his life experiences added to his understanding of teaching (West, 2018). This aspect of Ben’s story resonated with me and supports Qualter’s (1999) suggestion that aspects of PCK are informed by the teacher’s view of effective teaching, including child-led science that begins from questions. In secondary teaching his lessons had been more didactic and focused round the school’s schemes of work. Ben was surprised because primary children asked higher level questions than he had expected:

> What I found was that children ask questions - a lot of questions, not all children, but there are a lot of children that ask questions that are way beyond what is expected of them to know about. It is too easy to say you won’t understand that, that is GCSE - that is A Level, whatever. **I think** what they need is an explanation that they can **understand** that still addresses what they are saying but targets it at the age they are and… I think what I did quite well... not all the time, was get them to understand really technical ideas ... early on.

Ben’s presupposition is that the world is ordered, uniform and can be explained and effective science is where children ask the questions and the teacher helps them to find the answers. Ben does not consider that there are ideas that are too complex, only poor explanations, and holds a Vision I emphasis of solid foundations (Roberts, 2007). Children might only ask questions if they feel safe to do so but Ben suggests he can get children to understand technical ideas earlier than might be expected, reasoning ‘It is too easy to say you won’t understand that, ‘ and that ‘some teachers fail to stretch children because they consider them immature and not able to comprehend the science’. This is exemplified by an example in the first interview that concerned a teacher whom Ben considered very competent, but who in an observed lesson told the children:

> that the plate was sweating! It wasn’t actually sweating but I can see why she might say that. When I said to her can we **not …** perhaps use that word, but maybe something else. She said these are small children and they won’t remember.

Ben's outrage when recounting this story and others like it suggest his presupposition and those of this teacher differed. Ben described the teacher as good despite telling the children that the plate was sweating. However, Ben said he was, 'more than horrified because it was the wrong language, it provided the wrong scientific idea, and [he just saw] this was wrong!' The teacher believed she was using age-appropriate vocabulary and simple explanations for children, which they would not remember anyway. The level of Ben's anger was palpable, and I could still feel the anger and picture his face as I transcribed the tape. It also revealed the power a headteacher or 'expert' wields if they consider a teacher's action to be inappropriate or if there is no value congruence of ideas. Ben believes that science is about correct explanations (Roberts, 2007) and a sweating plate explanation could be damaging to the children and their long-term future because he understands Ben's curriculum focus is concerned with correct ideas and, if teachers underestimate learners, this will prevent them from engaging in the world of science.

6.2.2 Presupposition: Underestimating learners

Ben suggests that teaching science in primary school is about conserving the pipeline and that under his tutorage children had fun and were 'going further in their science learning journey'. Ben was using his hands to explain the trajectory of learning whilst explaining his rationale: 'we have to get the children from here to somewhere else – there', which is a lot further along:

> I think it is because it is finding the right language and here, I am struggling to find the right language right now ...to do it …to explain quite complex things at a level that children can get - not every child - but those who are really engaged in what you are talking about. I think all children can be engaged at a certain level and there are some children who take it further **way beyond what you might** expect and ask some brilliant questions. I think that what I am quite good at doing, is actually giving them an answer to that or helping them find an answer to that. It would be too easy to say don't worry that is way too complicated a question, so I think they then feel like they have got an answer to what they were setting out to find out, which others might have said don't worry about that - that is way too difficult.

For Ben science is for those who are really engaged in lessons and whilst 'children could be engaged at a certain level … and some can ask brilliant questions', the skills of effective teaching are to give children- 'not every child'- an answer or to help them to find the answer. As Ben believes that there is regularity and order in the world that children can gain access to through questioning. I asked what if the children's questions are not within the curriculum? Ben did not think that this was of concern and that as a skilful teacher it could be explained at a level that works for the child who asked the question. I reflected on my teaching and how my focus, at about this time, had been on the mountain of misconceptions (Claxton 1986) and noticed that this viewpoint was not present in Ben's account.

In Ben's first role with disaffected secondary pupils he struggled because the students did not engage in his lessons. Ben regained his sense of adventure when he became a successful primary science teacher. This success story is now examined in more detail focusing on the children's response to his lessons.

6.3 Personal style – feedback from the children

Qualter (1999) argued that good primary science teaching requires teachers to put aside memories of their own science education, but this is a challenge. Ben initially taught secondary style lessons in a primary school with some minor first-order changes (Cuban, 1993) in the organisation of the classroom and the curriculum. Ben remembers these early days clearly:

> I can remember that year in primary because the amount I had to do, to work out what I was going to do. To work out what worked as I was not trained at all in primary, I did a bit of English and maths but basically, I was trying to do secondary science in a primary school and the kids loved it. The primary teaching experience was hard but was so much fun, it was interesting ... it was worth studying ….some of it was exciting … not all of it though'

Teaching primary science was a joy, but Ben had to study to work out what the children could do and to find things they would enjoy. He said he worked hard at planning lessons because the children's feedback made this effort worthwhile. Ben quickly developed his skills and started to introduce more practical activities; as his thinking changed, he developed what he calls his 'primary approach' to science, by making many more second-order changes (Cuban, 1993). As Ben explained:

> I started to build practical activities, but they were mostly demonstrations and then I started looking for things that I could do which would be a lot more **wow** - you know stuff that would be really engaging for the children.

Ben was motivated to spend his holidays searching for materials and resources to make his lessons inspiring. He was prepared to spend time planning and to work in a practical way because of the way the children reacted to his lessons. Ben's lessons were successful, and this led to more successes, with his expectancy increasing with each successful lesson. Sang et al. (2010) in an ICT study found that teachers like Ben, who have high estimations of their personal teaching efficacy, are more likely to spend the time needed to improve. It has been suggested that having positive experiences and teaching fun and interesting lessons provided intrinsic rewards and greater motivation (Watters and Ginns, 2000). Teaching primary science gave Ben 'this buzz' and over time he became more successful and competent with dealing with the demands of the primary classroom. The children liked his lessons: the personality of the science teacher is important and has an influence on children's interest in science (Logan and Stamp, 2013). Ben described several lessons and the reaction of the children:

> In primary school there is something - it is just something about the way children react. It was like an adventure all over again. I don't know something like teaching forces, something you will have done over and over again and just bringing in a force meter - a newton meter - and getting them to start trying to find out how many newtons it was to open a door or just real basic stuff. The children were **beyond excited** about it because they had only experienced science where they were sitting at a desk with a textbook open and talking about things and writing things down and drawing things. They had never done anything practical, so everything was an adventure. It was an adventure for me because I had to work out what you **could do** with children of that age and what you could get out of them, but they were on an adventure too. It felt like I was meant to do it because it was so much fun - that is the **best bit** about primary science it **is so much** fun.

Teaching these kinds of lessons gave Ben back his sense of adventure and, unlike when he was teaching secondary pupils, Ben said he was taking the children on the 'adventure too.' The motivation came from seeing the children's excitement. There is an alignment between science learning experiences and science interest (Logan and Stamp, 2013). The children enjoyed these practical lessons particularly as the previous lessons had been text book based 'traditional teacher-centred lessons, where students have little input' (Logan and Stamp. 2013, p.2881). Yet Ben's science lessons were set within the context of policy and national tests.

6.3.1 Policy: Tests and test results, indicators of successful teaching

Ben identified that the children were making progress: 'measures showed that the kids were doing well'. These measures were the national tests for science, often called the SATS (Standard Assessment Tasks). Ben reported that his children did better than expected and although Ben suggested that these tests were unimportant, he recollects these results decades later:

> **I did not even look** at the National Curriculum. I came in the April and they sat them in the May and I think about 5% of the children got Level 5 the rest got Level 4. The following year I think we got something like 85% of them getting Level 5 and the rest got Level 4 but I had not taught the National Curriculum at all! I had done what was fun and what I thought was a good idea to do regardless of the exams at the end of it.

The previously the SAT results in the school were in line with national expectations or slightly above, but after one year the outcomes were significantly better. National test results have been used as an indicator of good science teaching, and as they were high stakes tests (Black and Wiliam, 1998), teachers taught to these tests (Harrison, 2001). There are issues with a simplistic, cause and effect approach, one of which is test motivation (Knekta, 2017) in attributing pupil success to the cultivation of enthusiasm.'

A discourse about the link between test results and quality teaching dominated science teaching during this period of education, with high-status tests being the success measure (Harlen, 2010).

Qualter even justified her sample of good science teachers by using performance in SATs as a criterion, identifying that half her sample had 'achieved higher levels than might have been expected in their SATs in science' (1999, p.80). There is a challenge with SATs in that they are high stakes for schools but low stakes for pupils, because there is little value to the children themselves. Knekta (2017) suggested that the way the tests were introduced to the pupils and the status afforded to them influenced the outcomes. The links between test results and educational standards are not proven and 'as test scores have risen, educational standards may have actually declined' (Wyse and Torrance, 2009, p.228). These tests results were a key aspect of the first interview.

Ben said he might have just stayed as a classroom teacher if these SAT results had not raised his profile and alerted his headteacher to his potential. 'She saw the benefit to the children and started recommending me to other schools and said to them this person can show you how to do some exciting things in science'. Ben went on to share practices with other local teachers and he explains the opportunities he was given to influence others to try new things was directly related to the SATs results his pupils achieved; they made him visible. He was very keen to work with others and learn new things.

6.3.2 The role of others

In primary school, after the children, his headteacher was the first important other in Ben's story, but he talked about the need to meet others:

> I started to meet people and that started to open things up for me, because the drawback of being in a small school is not having anyone to share those ideas with. I ended up just getting excited by myself but having no idea as to whether what I was doing was right or not, it was just a lot of fun - are you just allowed to have fun? Measures showed that the kids were doing well **BUT** I just needed people to bounce ideas off and to extend me.

Ben was enjoying teaching primary science but discussed if it was OK to have fun and if what he was doing was right. Ben said he developed his classroom teaching skills in science over the next five years but was still looking for support and ideas:

> So, I looked at places like the ASE [Association for Science Education] and joined that and all sorts of things, to find people who could do it - that was important to me - to get more out of it, to find other people who were interested in doing what I was doing.

The ASE is a national organisation which, was one of the biggest subject associations in the UK. Ben was looking for successful science educators 'who could do it' and he loved the courses he attended - in particular, the development of knowledge alongside 'knowledgeable others'. He said he needed resources and new ideas and these 'material and provisional outcomes' (Harland and Kinder, 2014) were linked to 'value congruence outcomes' (ibid, p.670), where his views and those who delivered training converged and confirmed that he was doing it right.

The ideas and methods that Ben tried out in his own classroom and in other schools eventually led to a nomination for the Science Teacher of the Year. Winning this national award provided additional validation and extrinsic rewards. He was now successful and, as a result, he started to spend more time in other schools, acting as a science consultant. He enjoyed this role and says he would have been happy continuing with both roles, but a conflict developed with some teachers in his school:

> Certain people in the school I was at did not like that sort of attention I was getting so they made it more difficult for me. I did not want to be in that place because they saw it as attention-seeking rather than enjoying what came from what I was doing. So that then influenced where I went next.

Ben said these people at school provided a fork in the road that led him to a new role. Yet without the skills and experience, arriving at this fork would not have been possible (Bourdieu, 1990). It reminded me of my own story, where I explained that my leap into advisory work was 'life changing' but like Ben it was due to others (in my case church governors) who I wanted to escape from. I came to understand further that life stories can be altered according to audience. If I had been recounting my life to a colleague who was interested in school governing, how 'my life changed' might have been told in depth. I did not ask how Ben felt about this push because in the same position I would not have welcomed that question.

6.3.3 Summary

The introductory part of this chapter has provided a chronological overview of Ben's teaching career and unpicks some of his motivations and beliefs. It is a story of changing expectations built upon his childhood goal to be a teacher and eventually running a school. This desire was strong enough to keep Ben in a degree subject that he loathed and teaching at a secondary school, 'where he struggled.' A chance encounter in a primary school offered an alternative path where he rediscovered the adventure and started working from the children's questions. Ben has been looking back on his life which is now very successful. His earlier biography enabled this to happen (Bourdieu 1990) alongside his personal style which required teaching to be an adventure. In the next section Ben's presuppositions are linked to his beliefs about science and society and what he considers to be important in primary science outside his school.

6.4 Presuppositions and motivations

In this section Ben's belief in the canonical, authoritative and accepted science, and the role of primary science in maintaining and encouraging more children to do science long term is reflected upon. The thorny issue of science and fun is also debated using the constructs of situational and personal interest (Logan and Stamp, 2013). The section starts with a discussion of Ben's views about how to encourage more children to take science.

Ben believes that children's ability to take science after primary school is influenced by the teaching approaches used in primary schools, but that there is also a bigger issue: that science is about 'engaging their brains', 'if it was done well', and the potential to increase the numbers of children who want to do science long term:

> **But** I think it can engage and I think if it is done well, there is the potential for more children to want to do it long term. But I think they get put off it much later on, but if we have that engagement … then there is a chance they will go 'there is something in this I have just got to delve deeper'. Science is really good at stimulating questioning, anything scientific gets children asking more and more questions, which means they are engaging their brains and that is **really** important! So as a discipline to actually engage in science is really good for all sorts of other things.

From Ben's perspective science begins and ends with motivation and engagement, where children identify there is something in this [science]. Ben thinks science stimulates questions, where the answers are 'unknown' to the children (Dunlop, *et al.*, 2015) but not to Ben. Dunlop *et al.* (2015) researched the community of scientific enquiry and many of their approaches support Ben's methods. However, there are differences: Ben prefers questions to which he knows the answers or where he can support the children to find the answers. He was not interested in questions where answers are not known or to approaches where the children are not learning 'canons of natural science' (Danielsson and Warwick, 2014a, p.104): Ben's core belief is that it is science that provides answers for questions, demonstrated below. He recognises that emotional attachment supports learning, (Salomon, 2013) and believes that children who are 'put off' science in secondary school might return to science if they have been taught meaningful primary science and know how to 'delve deeper.' Pupils' emotional attachment result from WOW moments which spark individual 'situational interest' (Logan and Stamp, 2013, p. 2880) and therefore influences pupils' perceptions of science. Situational interest is where something in the environment triggers interest (Logan and Stamp, 2013):

> 'I still need my WOW moments, in my science lessons and I still think they make a difference to children's perceptions of science. They are not the only thing. They are the starting points because I think you need hooks, so that children understand that science is exciting. If you want them to explore things, I think a lot of those sorts of things will really draw them in. I

> don't think they teach them a lot more science, but I think they draw them in and make them want to participate.'

Ben finds science fascinating and always had a personal interest because he did well in science (Eccles, 2009) which led to him to study physics. As a result, he believes that children's perceptions of science can be influenced by situational interest. Ben believes that motivation is related to the tasks and that a psychological dimension, a love of science, (a personal interest) can be influenced by the exciting WOW science. Hidi and Harackiewicz's (2000) agree and their review of the literature on interest suggested that personal interest was one of the most significant factors leading to motivation and learning. Ben believes that science has an intrinsic interest value that can be activated by 'hooks that pull the children into science' and whilst these activities might not teach 'a lot more science' they encourage the children to want to participate. This idea of hooks is not new and was called 'catch and hold' approaches by Dewey (1913) who proposed such approaches helped students to develop interest in scientific canonical knowledge. Ben has developed a strong relationship to science built on the idea of learning science as an adventure that helps children to find out about the world. In order to involve children in this adventure requires Ben to provide situations that change their perceptions and helps promote science as exciting.

6.4.1 Presupposition: canonical knowledge

Although practical work is thought to underpin effective science teaching (Holman, 2017), Ben dislikes practical activities where children develop an inaccurate understanding of scientific ideas. Unlike the approach of ASE (1963) primary committee (see section 2.5), Ben is convinced that correct science subject knowledge and facts underpin teaching science:

> I have seen teachers deliver what seems to be fairly credible science to children but is in fact wrong and that is a little bit of a concern. So, there is an aspect of that I think, I have seen quite a few teachers who teach in a practical way with the children engaged - they love the science - but the science they are getting out of it is incorrect and I think that is something that I think needs to be addressed.

Ben is articulating part of the paradigm of primary science: he identifies that teachers are not afraid to teach science and that children love the lessons but the science facts the children learn is wrong. Ben then recounted an investigation he had recently observed where the children were carrying out a comparative or fair test (DfE, 2013) about the distance someone can jump and whether it was related to the length of their legs:

> It was extraordinary, but there was no kind of reflection on what was going on - it was just ridiculous! We set up a practical, we tested it, we come back, we reported on it, we have done a good job haven't we, because we have followed the criteria of - you know - you

> identify your variables, you measure - you know - we have followed our plan, but it was entirely wrong!

Ben's concern was that the children's tests provided information that was inaccurate. The children had set out to examine a relationship, and the children changed variables, measured things, and recorded outcomes. Ben suggested however, the children had found out nothing scientifically 'correct' about their bodies, nor about variations between people. Ben said he had been observing and talking to groups during the lesson and identified that the results the children shared with the rest of the class were not even the results the children had obtained. To exacerbate matters, the teacher was happy with the lesson because children were working in groups following 'a formula and enjoying it, so science was great'. Yet for Ben 'there was **no** science that they extracted from it that was correct at all!'

The smallest child reported he had jumped the furthest (although he had not) and persuaded his group of these results. In discussion Ben said that it was not simply a case of the teacher lacking understanding of biology and, because the teacher was happy to get the children 'doing science,' neither was confidence a concern. Ben thinks this teacher and others like them, as poor science teachers undertaking what they think is effective science.

When reflecting on this section of the transcript in our second meeting, Ben asked for all identifying aspects to be removed and suggested the self-judgement of confidence was the problem: 'I would say that teachers are their own most harshest (sic) critics - except for the poor ones - who think they are good'. In Ben's experience good teachers reported that they were less effective, whilst poor teachers identified their teaching as good. As indicated earlier, the construct of self-confidence in science is problematic.

6.4.2 Examining the paradigm

The opportunity to discuss his life stories in subsequent meetings enabled both reflection and further discussion and whilst examining the first transcript together (which had already been shared and agreed as accurate by email) Ben identified that his focus had been on examples of 'wrong science.' Ben said: 'oh no there I am giving another example of someone saying something wrong, it seems I am a little obsessive about this (laughs)'. Mulholland and Wallace (2003) suggested this is the common behaviour of specialist teachers when viewing generalists. Ben had spent most of the first interview communicating the dominant narrative of teachers with poor subject knowledge lacking confidence but in the second interview he said:

> It is astonishing that there are people peddling that people in primary are rubbish. I started in secondary and I knew that right from the start - and I probably 'bought into it', because

> you are surrounded by people who think that primary schools are really there to see them up to you and then you are going to teach them the science. I think we did have that kind of indoctrination if you like.

As identified in the discussion on beliefs (Section 2.3) it is difficult to challenge what is known and the narrative of poor primary science teaching is accepted. In his final interview Ben focused more on best practice:

> I saw a guy recently and I think he was possibly the most skilful primary school teacher, forget science teaching, that I have ever watched teach. I could have sat through his lessons all day long, because he just had an amazing…an amazing ability to generate a classroom atmosphere that just delivered on every level. There were kids, totally engaged - they were hanging onto his every word from the start to finish of the lesson

Ben said, 'possibly the most skilful primary school teacher, forget science teaching,' in his view, this teacher was skilful across all subjects. He went on to explain that not all the science teachers whom he would rate as good had science degrees, and in his terms, they are not 'scientists':

> I think there is a lot of very good science teachers out there, but they are not all scientists they don't all have a science background and I think that what makes exceptional science teachers are people who are prepared to work out good ways of preparing and teaching, whether they have a science background or not.

Ben's role now enables him to watch qualified exceptional science teachers, he discussed what he thought was the secret of good science teaching:

> The primary teacher is more likely to teach great primary school science given the ideas, support with the way to go, the things to do, than someone who knows loads and loads but does not have the skills to teach at primary. So, I for example, I know lots of secondary school teachers who have fantastic science knowledge who will never be able to inspire children in the primary - at primary level. Over the last few years I have seen really, really excellent primary school teachers doing real science: they would say that they are not scientists but they have developed the love of teaching science so they feel comfortable in providing lots of activities which will engage the children, to set them on that path which is what we want them to do. Which is to learn through exploring and doing and become like a scientist, see things happening and just want to find out a reason why. They don't necessarily follow a plan to do it, don't necessarily build up step by step in a certain way, but just find activities that interest the children and let them explore things together, they make great science teachers!

This was a change from the first interview, and I wondered if Ben's change in role, from a consultant supporting teachers in difficulty, to a role identifying outstanding teachers was instrumental in this shift. Ben's example of an inspiring teacher, where the children 'were hanging onto his every word from the start to finish of the lesson', demonstrates Ben's belief that effective teaching includes the performance skill of the teacher. For Ben the role of primary science is to put children onto the path to become a scientist. Ben's reflection on the effective teaching of science also highlighted the role of teacher's subject knowledge:

> There is a difference between a teacher who says to the class 'I don't understand what's going on let's find out together' and they do something scientific to find out an answer to something, and a teacher who looks at a practical and then tells them something … that tries to describe the science to them, explains the science to them and gets it wrong! I see really good teachers and they are not doing that, they are saying – 'What can we do?' 'What can we see?' 'Can we explain from this what we know?' 'What can we see here?' And all that sort of stuff and they are not peddling nonsense! It is better that they don't peddle nonsense - it is better if they say, 'let's find out', which is better than to talk rubbish - as rubbish is very hard to get rid of!

This is different from the teacher as the all-knowing sage (McWilliam, 2009) and whilst this is a change from Ben's earlier advocacy of the skilful teacher who answers all the children's questions, there is still a strong resistance to 'peddling nonsense and talking rubbish', because 'rubbish is very hard to get rid of.'

6.4.3 Presupposition: Primary Science should be fun

Ben knew that teaching primary science was for him: he says, 'it felt like I was meant to do it because it was so much fun; that is the **best bit** about primary science it **is so much** fun'. The debate concerns the role of primary science and whether 'fun' is an appropriate outcome. In the TED Talk 'Should we stop trying to make science more 'fun'?', Archer (2015) suggested that making slime, exploding cola, or blowing things up is an approach that teachers develop to try to make science fun for the learners. However, Archer believes that not only is this approach insufficient, but it is also misguided if the long-term objective is to get more young people into science. The ASPIRES project found that interest in science lessons was not the issue; a finding supported by OECD data (2007). The problem was that learners do not go on to science careers, suggesting there is a mismatch with science education practices and science in the world which results in the leaking pipeline. Archer *et al.* (2015) determined that if learners are to go on to study science post-sixteen, they need to develop a science identity. Archer *et al. (2015)* use the term 'science capital' to explain the factors that influenced this science identity and that fun activities are not important but instead learners requires experiences of science from everyday life to build 'science capital' (Bourdieu, 2004).

Ben was inspired by the motivation of being a successful science teacher. He attributed this success to the children's outcomes and their joy in his lessons, as well as the intrinsic motivation of personally finding his place in the education system (Watters and Ginns, 2000). Yet it was not just Ben who was having fun, he reported that 'the children's reaction was phenomenal! There is no better buzz than having children who are almost cheering in your lessons'. Having 'beyond excited' children is motivational and focuses on the affective domain, although Jocz *et al*, (2014) also recognised that activities where the children were excited may not be true indicators of long-term learning or engagement in science, as some of the lessons that teachers identified as fun, the children did not remember. Instead the lessons which involved group work and science related to everyday life were the lessons which had the greatest impact on science learning (*ibid*). This involvement of examples of everyday life in science teaching is important and will be returned to in other biographical chapters.

6.4.4 Summary

Ben has expressed a belief that effective teaching starts from engaging the learners but that teachers must give correct answers, so there can be no 'peddling of nonsense'. His approach is predicated by a belief that science in primary schools will nourish or sustain these learners when science becomes harder later in their education. Ben has a view of scientific knowledge and describes himself as a scientist. He is unforgiving of incorrect science subject knowledge and always expresses a need for correct scientific language and facts. He does not make the simple causal link between subject knowledge and effective teaching, and his ideas changed after he identified he was 'a little obsessive' and later he gave examples of positive teaching which were not dependent on strong subject knowledge. Some new conflicts will now be exposed as Ben discusses his view of science for all children.

6.5 Personal Style and Biography: Science and future scientists

Ben is very clear about who he considers will be successful in studying science and who therefore could become a scientist. This view is expanded upon and links are made to neuroscience. It is built partly from Ben's biography as a successful science student and from his presupposition that science is hard and challenging. Bruner's (2012) belief that stories are created by society and mirror what society comprehends is evidenced in this section.

6.5.1 'Making- it'- wiring the brain.

Ben states that teaching was what he should do, what he was born to do and would be his career. Ryan (2003) suggests that many who train to be teachers have a strong commitment to social justice and equal opportunities. The issue concerning 'science for all' has been evident in this chapter where Ben specifically suggests 'not all children', (section 6.2.1) 'not every child' (section 6.2.2) can benefit from science. Ben's view of science is informed by biography, and his grammar school education where his group of 'bright friends' all studied science, and his study of physics, which he ended up hating, resulting in him developing his presupposition that science is hard:

> I have met lots and lots of people who say the one thing about science is that it is the one thing that our least able children are able to do really well. Now I am not saying that the less able children can't get a certain amount out of science, do fairly well in science, but science is a complicated subject.

In the first interview Ben made the clear distinction between 'doing fairly well' and 'getting a certain amount out of science' and 'the possibility of becoming a scientist'.

> I think some people's brains are wired differently …that does not mean they can't all enjoy it at primary school level. I think they can in the same way I can enjoy things I won't go on to do anything else with in life, that I just won't be very good at (laughs). I don't know … I am not …I think it is important to understand the world. I do, I don't know why I do, but I do. There are certain things which I just think are important. It is important to understand the world and science gives you a means of understanding the world. So if you are a child you are naturally born a scientist, the desire to explore, make sense of things, is natural - absolutely and if you can engage children and take that further, at an early age, doing what they do naturally, I think there is more chance of them long term still being interested …. But there are some people that won't be, whatever you do, but that is why I think primary science is important.

There is a conflict between science as the way all children learn naturally, the narrative of the child as a scientist, and science as the ultimate form of knowledge. The statement that 'science gives you a means of understanding the world' could be viewed as a larger statement about realism and science (Kitcher, 1993) and elements in this excerpt mirror some of the common narratives about children as curious explorers.

6.5.2 Attainment and ability

The question about what was meant by 'science for all', and if there are some children who are 'born less able', was something I pondered upon. In the second interview these ideas of ability were deliberated further together. I asked what Ben meant by his previous comments:

> But I don't mean that, that is awful, and I don't believe it is - because I don't think they will ever will. But then that is like categorising them as a group and I think that is unfair because less able in a way, a person is not less able you can be brilliant in one aspect and not in another.

Ben does not consider that science is for all children: 'I don't believe it is – because I don't think they ever will' [become scientists]. Ben tried to explain this complicated view in terms of him and how he was useless at P.E. Yet this lack of ability in P.E., he suggests, should not make people view him as less able but just not as competent within this domain. He went onto use the term 'valuable' in his attempt to explain his dilemma:

> So, I would say if there was a special need in terms of P.E., I would be in that category. But I would hate for someone to view me as 'less able' because I am really, really useless at P.E. So, if someone struggles more in science that does not necessarily mean that they are less valuable - I would not want that to come across but I think you have to be a pretty good mathematician and not everyone will be in life. I think you have got to have a fairly 'sciencey' brain, I think there is a science brain in there somewhere.

This discussion made me ponder about domains of knowledge, particularly specialised vertical knowledge and was influential in the development of the vertical structure model. Ben identifies that in different subjects have different requirements. Biology and the 'sciencey brain' are the lenses through which Ben comprehends differences in perceptions of, and attainment in, science: scientists are not every day people. This view is informed by his biography but is also an example where narratives can reflect society (Bruner, 2012) as neuroscientific ideas have entered the educational narrative and 'the notion that students (or more specifically, their brains) can be tidily grouped into categories such as "typical" or "atypical" (Busso and Pollack, 2015, p.172). In the aptly-named article 'No brain left behind', Busso and Pollack raised concerns over the increasing focus on contemporary biological and brain explanations for educational outcomes. Ben, however, questions the role of science for the less able children and communicated this viewpoint in more than one interview:

> So somebody may be less able in science which does not mean they are not brilliant in other aspects - so just to clarify my stance on that, I think I have seen it said, several times that, on a number of occasions, for example, when people have said to me 'we love science at school because our less able pupils are able to do it more than our more able'. That is our traditionally more able pupils, sort of thing. When I am trying to explain - that you have pupils who can't write anything, can't do the maths but they are 'brilliant at science' because they can set up the practical work and they can go wow! There is an element of that, you can see something and understand the science without necessarily being able to write it down! But I think long term you can't be a good, proper, no not proper that is not the right word, a good scientist, if you have not got the ability to, they become very difficult subjects and if you have not got ability in these areas then you are never going to succeed in science.

Ben views educational ability in science as being directly related to ability in maths and an aptitude to cope with complexity, rather than being able to 'set up the practical work and… go WOW.' Ben likes and is good at maths. There is nothing in the interview that demonstrates that Ben is aware of other social or cultural explanations for why children might not succeed. The issue for Ben is about complexity, whilst for other teachers it is about children who can explain what they see. I do not know which is more important –understanding mathematics and being considered 'bright' or to have a love of puzzles and the intrinsic motivation to keep finding out. Long term Ben is looking for 'proper scientists' and does not believe that less able children will ever be 'proper'. These proper scientists, potential scientists or smart kids (Costa, 1995) already have an aptitude for science and can envisage a science worldview, but research suggests they do not need science to be entertaining or made relevant to their life, because it already is (Costa, 1995, p. 318). Although Ben considered that science is not for all he still considers science in primary schools as vital for scientific literacy reasons.

6.5.3 Scientific literacy and acting like scientists.

Ben expresses the need for scientific literacy, and returns to his science and complexity argument, demonstrating that he wants all pupils to have a scientific mind:

> I do think that sometimes we make children think that science is great, and I know they are never going to be able to do anything with it in their lives because they are not going to be able to cope with the complexity of this long term. That is a terrible thing to say because I want, I want lots of very - I want people to have a scientific mind, I want them to be able to be critical of and about science - but I don't believe that - so I want them to be able to read a newspaper article and think and not take it on face value - to be able to question it reasonably - I want them to be able to judge arguments in the newspapers that are either one sided or the other and to see it is not always straightforward to read something - I want people to act more like scientists! To be a little bit more critical about what they are reading to understand the science that is presented to them, but I don't believe that actually that we will particularly make more scientists because I think a certain person becomes a scientist.

Ben embraces a textbook view of scientists and wants all people to act like the scientists portrayed in the books. He questions the stories in the media and suggests that if children are scientifically literate, they would be able to spot issues with pseudoscience. Ben's view of scientific literacy focuses on the democratic and the utility arguments. The democratic argument suggests science enables future citizens to reach an informed view in order to contribute to society (Driver, Newton and Osborne, 2000). The utility argument instead suggests the population needs to understand science, so they can function in society.

Ben's opinion about who can become a scientist has been included because of the number of times it appeared in the transcripts. However, it would be fictitious to suggest that this thread was not also identified in my analysis because it is so foreign to my views. It does, however, draw upon the dichotomy between the science and non-science brain and demonstrates that Ben does not have any grey areas of belief. Talking to Ben provided information about his scientific worldview and in order to really understand Ben's viewpoint it is necessary to complete this chapter with his view of the sciences.

6.6 Presuppositions: The role of society and the Sciences

In this final segment the notion of the sciences, not science education, is the focus and draws heavily on influences that have provided Ben with his view of science outside education. These views inform the activities and approaches that Ben adopts as well as his belief that science is the way to understand the world.

Ben has a clear view of his perspective on 'what science is' and 'what science achieves'. This view is influenced by his background as a secondary science specialist, working with advisory teachers and subsequently becoming a consultant. So, when asked what he thought science is, Ben's explanation was clear:

> I think it is a means of describing the world around you, a means of understanding the world around you and producing ….ways of … describing things that others can replicate. .. So, science is about, not only seeing something and observing it, but gathering data which is replicable so that you can prove something to somebody else. But not all the time, so there is lots of 'you do this science' to show somebody how something works and you gather data and things and I am not a highbrow scientist so I can't say, but it is also about pushing the boundaries and discovering how you can make the world a better place and in some instances how you can make the world a worse place. It is about change, it is about developing things that solve problems, it's about just about everything, it just goes on but I also don't hold the view that I understand that science is in everything, but I don't think that makes everyone a scientist.

Kitcher (1993) would identify the legend of science in this reflection where science can make things better but also makes things worse. Ben recognises that science is about change but there is no clear distinction between science and technology (Wolpert, 2000): science is about gathering data to prove things or show how things work. This stance is related to Ben's study of physics and the idea of complexity where not everyone is a scientist. Ben said, 'it is quite fashionable to say this hairdresser - she is a scientist because she uses science, but she does not really'. The 'science-in-society' perspective of science in hair dye or in cooking is not science for Ben - his science lens only values pure science. Ziman (1984) would suggest this is an example of the mismatch between some science educators and the motivation of the children they teach, as children develop their understanding of the world and bring their own interpretations. Ben holds an educationalist's view that becoming scientifically literate involves accepting the values, methods and concepts of science and coming to seeing the world in a scientific way, which is contradicted by the research on science capital (Archer et al, 2013). It is also an approach that Cobern suggest is 'alienating and pointless' (1996, p.597). Ben's scientific worldview could be thought of as an elitist one where the role of science in hairdressing has no 'coherence with his beliefs' (Thagard, 1994, cited by Cobern, 1996, p.597).

As Ben viewed some things as science and others as not, I asked Ben to define science 'I wonder if it is harder to think what is important when you are a scientist, than if you were a non-scientist. I think what you perhaps ought to do is ask someone who is not a scientist – 'what science is?' because if you did this, they would say science is …blur …then part of me would be able to have something to say about it!' In order to help Ben, try to develop a definition of science, I shared some of the views of non-scientists (Latour, 1987; Rorty, 1982) about the nature of science - as only one way of looking at the world. His response ends the chapter as it explains his viewpoint without the need for any further explanation, but this view will be returned to in Chapter 10.

> I would say 'bollocks', that is what I would say (laughs). No, I would say that science offers the best way of describing what we know from the information we have got at that point, it is not always right but is the best way we have of describing what we can see at the moment! But whilst it can change you have, definitely have, information you can base things on.

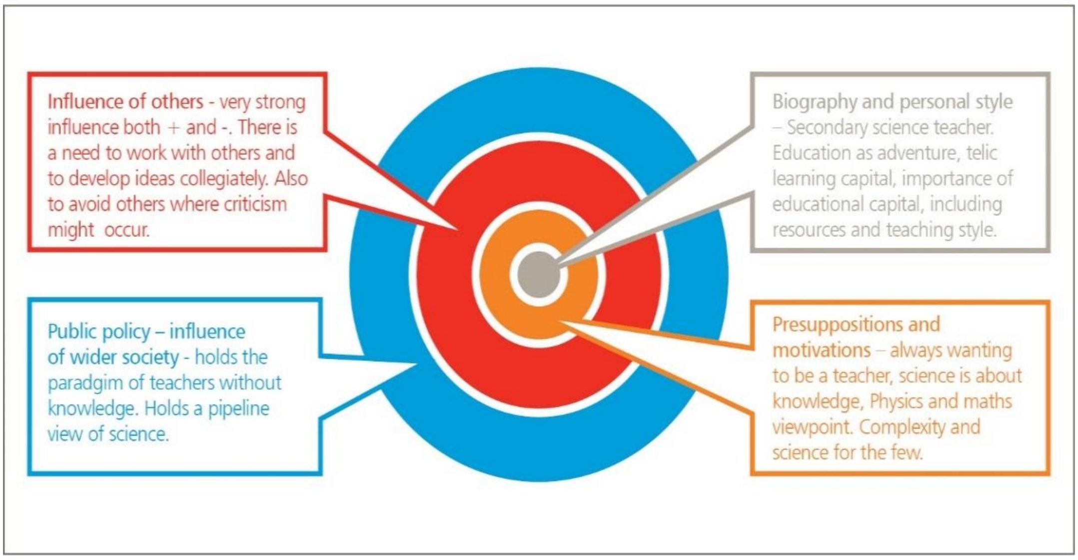

Figure 7. Ben's sphere of Knowledge creation

6.7 Summary

Working with Ben challenged my thinking because I have always thought that science was for everyone. Ben's view of science as legend (Kitcher, 1993) was like my view point prior to beginning this study. Ben was encultured into science in his school years; he liked the way science made the world seem understandable. This was not the worldview of his physics degree which he hated. Working with Ben made me challenge why I held a science worldview and how I accepted only in later life the narrative of scientific literacy. Ben does not express a constructivist approach to teaching but does include the importance of questioning. Working with Ben made me examine positivist approaches and also empiricism. In the next chapter Stephanie made me reflect upon the Big Group and science in the world.

Chapter 7: Stephanie - Loving science, science as a way of life

7.1 Introducing Stephanie

This Introduction provides a context for this biography and background information about Stephanie and her setting. Stephanie's presuppositions about science and her motivations are discussed but her personal style and biography is the starting point. Stephanie is a science adviser within a Local Authority, a role that she has held for more than 30 years. Stephanie works with many other Local Authorities. She has been active in national organisations such as the Association for Science Education for more than 20 years. As a practitioner who created new approaches to primary science, she was instrumental in many initiatives both in the UK and abroad. Owing to Stephanie's profile, it would be difficult to work within the field and not know of her, although before the interview I had no idea of her biography. Stephanie is aware of her profile and feels her story is unique:

> Yes, it is interesting then because the idea of trying to be anonymous as I suspect that I along with a number of other people, my story is fairly unique. So as soon as you start telling anybody – it will be clear even if you start trying to anonymise it.

As I have come to understand Stephanie, I realise that her role defines her and is her identity, and any perceived damage to this would be devastating. I have met Stephanie on many occasions at conferences and science meetings. Stephanie is a confident presenter and at the time of the first interview was actively involved with primary science education, both within her Local Authority and with the wider science community. This interview occurred after a conference and was audio-taped and transcribed. Where Stephanie adds stage prompts these are included in brackets. When talking she acts out the parts of the interview, which is more difficult to present as part of the text but has been included in brackets in a similar way to stage notes. Throughout the session, Stephanie used many hand gestures to signify a range of things within her recounting. For example, for the three groups of children in the class she used a cupped hand as well as circling gestures. Stephanie is a very engaging speaker and uses different voices for the characters that occur within her story.

Stephanie checked the transcript and no changes were requested, and she agreed to discuss the interview and themes. Then there was a change in one aspect of her national work, something she was very passionate about and, as a result, she has withdrawn from all her previous science work outside her Local Authority. I took the decision to change or remove any identifying aspect of her story to protect her from any risk (Josselson, 1996). I used the SKC to examine the biographical material (figure 4) and again have coloured coded the sections.

I initially selected small segments of transcript but realised that in order to get a real understanding it was necessary to include longer segments. The biography began with the question 'How did you get to be where you are now?'

7.2. Biography: How did you get to where you are now?

> It is quite interesting because actually because I am in this business as I am a failed … I failed to get into medical school. Which is an interesting concept … Ur because apparently the family story is that the first words, I spoke were I am going to be a doctor when I grow up.. so, you can imagine that the next 18 years everything I did was about that, St John's Ambulance, A Levels, the whole works, even going to boarding school in order to have a settled education and I failed to get into any medical school. And I (cough) ended up um ... at university and when I went into my first lecture that was when I discovered … So, I got a university place to do P.E./Sport and when I turned up to the first lecture, I discovered it was a teacher training course (grimace).. and I was going to do secondary P.E. But I had a horrible first term's experience, was not brave enough to quit and was conned into doing a primary experience in the second term ... loved it, transferred to primary, got a primary job to be a generalist, and at the end of the first year of working, as is the case in primary schools, suddenly there was a whole load of maternity leaves, so two of us found ourselves responsible for the whole curriculum between us.

It may appear peculiar to find oneself unexpectedly on a teaching course and is against the view of an agentic explanation of career choice 'rooted in the core belief that one has the power to produce effects by one's own actions' (Bandura *et al*., 2001, p.187). Stephanie narrated her story in this way to explain how she became a primary teacher. The use of the term failed was a surprise as Stephanie is not a failure, but she was disappointed she had not become a doctor. A course in sport was acceptable, but to become a primary teacher - where the qualifications and standing was not high (Gillard, 2011) perhaps required a story of unexpected outcomes: things happening to Stephanie rather than her taking control. Stephanie's story has verisimilitude (Bruner, 1989). Later in the interview, I returned to Stephanie's earliest memory to find out more about the desire to be a doctor. In Stephanie's transcript, the story of the first words is a strong influence - Stephanie desired to be a doctor and her goal had been to go to medical school:

> Yes .. um .. I .. the only thing I can put onto it is incredibly .. my mum's three brothers were all doctors and although all her family are based in Australia … so I had never met them and mum had only talked about them ... how they had been with the Australian services, how they had gone as doctors to Vietnam and they had come back from there and one was still a doctor but the others had gone into emergency services … St John's and all that kind of business. It was something that I heard a lot about but never actually really witnessed it, but all these tales about it … and as I say the family rumour is that those were my first words spoken … so it almost goes back to ... I don't know really know why, but almost before I really thought about it … obviously the seed was set somehow … .

The ASPIRES team suggested that research into why students take science-based courses post-sixteen, how 'the seed is set' had been 'little researched'. Although, Kennedy, Quinn and Taylor (2016) identified more than a dozen research studies into this issue since 1982. The ASPIRES project suggests that lifeworld experiences prior to 14 are the major determinate of decisions to study science (Lindahl, 2007; cited by DeWitt *et al.*, 2013, p.1038). There are concerns about the accuracy of research into attitudes and aspirations, which like confidence, revolve around what is being measured and how. Stephanie attended a private boarding school to gain a 'settled education' to enable her to reach her goal, the goal of being a doctor was encouraged by her mother. The influence of parents and the child's belief in their academic ability has been identified by others as an influence on future attainment (Bandura *et al.*, 2001; Eccles and Wigfield, 1995). Stephanie's mother reminding her of her first words suggests she held a positive view of Stephanie becoming a doctor, following in the family footsteps. The ASPIRES research proposed that attitude to science and a positive image of science were equally important for future aspiration of a career in science.

Future aspirations are clearly linked with motivation theories which no longer simplistically classify motivation as intrinsic or extrinsic; identifying instead that there is a continuum (Ryan and Deci, 2000). Motivation is not a unitary phenomenon and there are different types and amounts of motivation (ibid) Stephanie's story includes aspects of *introjection* - wanting to be a doctor to please her mother and follow in the family footsteps and *identification*- where Stephanie identifies that doing well will result in her ambition to be a doctor (Ryan and Deci, 2000, p. 72). Her expectation of being a doctor would set her as a potential scientist (Costa, 1995). Although in discussion with Stephanie it was clear she did not hold mastery goals (Lee et al., 2010) which are linked to an interest in a subject, (for example, science subjects), but instead that she held performance goals (wanting to do well) and such performance goals are linked to self-worth (ibid). Stephanie could not remember ever having been taught science in her primary school, so like most participants within this study, her attitudes and motivation, self-concept and parental influence were not related to her own personal experience of primary science. Stephanie did not demonstrate in the interview a love of science at secondary school. Her experience of primary science began at the start of her teaching career where she found the strange thing called science.

7.2.1 The role of others: The Strange thing called science

After qualifying Stephanie 'got a primary job to be a generalist,' and found herself leading the curriculum with another colleague. Stephanie had a teacher training qualification in education, with

A Level science subjects and a specific interest in P.E.; when Stephanie began her teaching career, primary science was not a compulsory part of the curriculum:

> So, two of us found ourselves responsible for the whole curriculum between us and there was this strange thing called science. So, I started attending a couple of sessions and fell in love with the thing. Because of what I was suddenly learning about science that I did not know before and what I was doing with kids and seeing how they reacted to it as well and it was kinda zoomph … um.

As a generalist with a love of PE, Stephanie began to attend primary science courses in the time prior to the introduction of the National Curriculum. These courses changed her view of science ('what I did not know about it before') and she developed a passion for science– (*'fell in love with the thing*.') Primary science research does not emphasis love, which is a strong emotion signifying the influence of the affective domain. Although cognitive measures abound in science education, measuring or promoting the affective domain could lead to suggestions of brainwashing and/or indoctrination (Laforgia, 1988). Stephanie's 'what I did not know about it before' establishes the beginning of her new understanding of science. Stephanie says that her intention to become a doctor had her immersed in the scientific fact aspects of science; these primary science sessions opened her eyes to a different type of science and indicated what could be achieved and what was important. 'This strange thing called science' seems peculiar now that primary science has been part of the curriculum for decades, but Stephanie's story coincides with the commencement of a new era for primary science (DES/WSO, 1989) where she found the support of the science adviser. She was developing specialist understanding of primary science within her newly developing specialist domain of teacher knowledge. Stephanie's science life story is heavily influenced by the role of her mentor who shaped her presuppositions and motivations:

> He was the guy whose courses I went on and having gone on a couple of courses, I then went on a course with him and kinda said some of the sort of things that I had done as a result of being on previous courses with him and how I had done this ... and the next thing I find myself having 5 minute bits within his courses.

As a result of attending these science courses led by the science adviser Stephanie gained access to a developing reservoir of culturally shared knowledge - 'what the primary science community at large knows'. Primary Science was not commonplace and was 'taught by class teachers with few science qualifications or none at all' (House of Commons, 2000, 6.4). As discussed in chapter 1 and in Ben's story, the influence of the adviser was pivotal at this time in education (Qualter, 1999), as advisers developed primary science into something unique and different from secondary science. The sharing of this worldview of effective practice concentrated upon 'value congruence' (Harland and Kinder, 2014) which is complex, multidimensional, and not directly linked to competency. Stephanie developed her 'individuated codes of practice' (Harland and Kinder, 2014, p.671) which over time coincided with the adviser's messages about good practice. Stephanie, like myself and Ben, adopted ideas that worked (Appleton, 2003) in her classroom with her children, which she then shared with both the adviser and other practitioners on the next course. The developing congruence resulted in the advancement of Stephanie's understanding of primary science. Yet there was 'trouble' (Bruner, 2004) brewing.

7.2.2 Importance of Recognition

Stephanie became a regular presenter, providing the classroom authenticity to the courses. Bruner's (2004) view of life as a narrative is useful, as up to this point the trouble had been the failure to get into medical school, closely followed by a dislike of teaching secondary P.E. and not being brave enough to walk away. Stephanie found her niche in primary teaching where she instantly felt she belonged. At this point in her story the agents are Stephanie and the science adviser together creating science opportunities for Stephanie and her class but also for the other participants on the courses. Stephanie's goal then became to do more of this. The activities she undertook in her class began the development of her identity and recognition as a primary science specialist. She was enjoying teaching primary science and seeing how the children reacted to these new ideas. Her response revolves around the emotions of elation, excitement, and happiness, all commonly described by teachers (Turner, 2009). Stephanie accepted the values and approaches presented and embraced this strange thing called science. Trouble, though reappears, rekindles a fear of failure, and challenges Stephanie's new identify:

> So, I was sharing these things and then the authority said 'there are these jobs coming up … if we get the money would you go for it?' Well … do what I am doing in my school … in more schools? And then the Authority did not get the money and then the other half of the Authorities in the country did, so I applied for those jobs ... and it was medical school again … all over. And I did not get a look in at any single one …. not surprising … because only my Authority knew … I had been around for such a short period of time but that I had a lot to offer.

The problem with an interview and not a video is the ability to convey certain emotions: when Stephanie said 'well … do what I am doing in my school … in more schools?', there was an incredulous tone of voice accompanied by a shrug with hands facing the ceiling – a view expressed that was 'why would anyone not want to?', all in a few words! I could relate to this feeling of recognition. Carlone and Johnson's (2007) research highlighted that recognition was imperative. Although they did not collect data on performance, the data they collected on competency showed this was not a significant factor, which again questions whether ability is important. In a later study

Carlone *et al.* (2010) went on to suggest that teachers' identity is determined by biography - 'establishing self in teaching and establishing self in schools' (Carlone, Kimmel and Tschida, 2010, p.143). This would support the idea of biographical learning, which was evident in Ben's biographical chapter and is linked to PCK (Shulman, 1986) and the suggestion that overtime teachers get better (Guerriero, 2017). Stephanie was identifying herself as a science type of person, but because competency and self-belief is not as important as recognition, Stephanie needed others to identify her as a science/non-science teacher. Stephanie was enthusiastic and intrinsically motivated by the inherent satisfaction of the science activities, resulting in a strong positive emotional experience to science teaching which enabled her to gain new understanding and developed her 'Self' (Dewey, 1913; Ryan and Deci, 2000). Yet outside her Authority she did not have recognition, and this limited symbolic capital (Bourdieu, 1986) was because she was only a recently qualified teacher.

Primary science was new, and Stephanie now had instrumental reasons to carry on: Stephanie wanted to become a specialist and do science all the time. Stephanie did not give up and was further '*encultured*' (Martin *et al.*, 2000) or assimilated (Aikenhead, 1996) into the developing role of primary science as she continued to work with the adviser. Later Stephanie had the opportunity to star on the bigger stage, teaching those people who had got the jobs she had applied for. This was to lead to a change:

> Incredibly those people, in those Authorities, took their positions up and in the October time in the south there was a conference for about 300 of them and the adviser was invited to do a session to say 'well this is how I have worked so far' *et cetera*. And he insisted that I came along and co-presented with him. So, I was telling all these people how to do the job that I did not get. And at the end of that year the Authority did get the money and here we are coming up to .. and September will be the start of year number 30.

Stephanie knew she was capable, but, as Carlone and Johnson (2007, p.1991) argue, that is not enough: an identity requires the recognition of others, for example, by a context-dependent credible performance, such as speaking at this conference. Stephanie says she had a lot to offer and when the Local Authority did eventually get an Education Support Grant (ESG), she achieved her goal. Stephanie continues the story of what happens after the Authority received this ESG funding:

> [A]nd the whole authority .. as far as I could see, just assumed that I was one of the people who would have this job … I had to go through all of the process and that sort of thing and I got it and there were a team of four of us. And at the end of that year the other two who were at my level in the team, suddenly announced they were off to headship and deputy headships, but I said 'this is a three-year project'…. to which the inspector says, 'well I never expected anyone to stay that long' .. so, they made me deputy head of the team. So, I trained up the new people, inducted them and carried the work on.

Stephanie's story might explain why she stayed in the role for the full term: it was not a stepping stone to something else, this was her role. She had achieved her goal and Stephanie worked with the team until the funding ended. Then her mentor took a role outside the Authority, leaving a gap for a science adviser. Stephanie had built her identity around the role but still appears hesitant about the prospect of rejection:

> [T]here were a few mumblings out there so I thought I won't go for it. If anyone else wants to go for it ... five minutes before closing date no one had gone for it ... so as I had nothing else to do at the moment. So .. I applied ... got it.

Telling a difficult part of one's life story is a challenge and Stephanie provides some context: 'there were a few mumblings out there', other people, competition, and fear of it being like medical school again. Perhaps this is not astonishing as Stephanie's identity is linked to her role in science: she is the science adviser, a role she loves and has stayed with for more than thirty years. Also important is her vision for children - that they will love science too.

7.2.3 Summary

Stephanie fell in love with primary science, a love that has continued to develop over time. Although Stephanie had no childhood ambition to be a teacher, she has stayed within the education system and within primary science education for more than 30 years. Primary science influences her affective domain and has become part of her identity. There was clearly a childhood dream and a sense of failure when this was not met. The feeling of 'it was like medical school all over again' is still articulated by Stephanie thirty years later. Stephanie became successful because she was able to demonstrate exemplary practice of 'primary science' teaching, something she did for more than three decades. Stephanie's presuppositions or vision of science, her view of the nature of science, and what Stephanie perceives is effective primary science teaching takes her story forward.

7.3 Presuppositions and motivations

The economic vision of global prosperity driven by STEM professionals, the neo-liberal argument for science education (Hollins and Reiss, 2016), has a limited value for Stephanie. As discussed previously, the goals for science education and the role of science literacy are not universally agreed (see section 3.5.2). Stephanie is of the opinion that everyone should have a working understanding of science as a right (OECD, 2000) as demonstrated by her discussion of children in three bunches (see below). She appreciates the canon of science - the understanding of scientific concepts (Danielsson and Warwick, 2014a) but is personally motivated by the role of science in society, the children 'who are going to live and experience life because of science.' This challenging issue of the role of science is one that Stephanie addresses initially by identifying that children come in ‘camps and bunches’ and her interest is in science for all.

7.3.1 Camps and bunches

[Here Stephanie uses her hands to signify the different groups]

> In the sense that the kids fall into three different camps. Those who … which most people think about ... who are going to go on be the scientists of the future ... which are sadly few. A middle group that are a kinda bunch who are going to work with science in some way in their work and then another bunch, who in a sense are going to live .. and experience life because of science and … they need to be .. I suppose that is the end of science literacy.

Stephanie expresses a view that most people consider only the children who are going to be scientists, whom she acknowledges are going to be ‘sadly few’. Instead she suggests:

> I am very mindful that actually in this group ... in your class ... there is that big lot [more hand gestures about the group who are not scientists or those using science] and if you are doing this stuff .. with them you might well lose them so hence you have to do things in a way that actually brings them along with you at the same time as enabling this lot [Gesturing to the other end of the spectrum of the scientists] to benefit and get what they need at the same time.

The paradigm, that states the lack of teacher expertise results in limited teacher confidence and results in poor pupils’ perception of science, emphasises the importance of the pipeline of scientists but, in discussion, Stephanie suggested that there are some children, who find science hard, particularly if a textbook, fact-based approaches are used. Such approaches fail to engage them and as a result the teacher ‘might well loose them’. Yet there will be children in the class who will become scientists or will use science, so the challenge for the teacher is to benefit ‘all camps or bunches’ at the same time. Although the interview was conducted before the widespread dissemination of the ASPIRES project, Stephanie’s long experience in schools supports some of the findings of this research, where ‘40% of students agreed that they would like to study more science in the future, 29% would ‘like to have a job that uses science’ and 31% even think they would be capable of being good scientists, only 17% agreed that they would like to ‘become a scientist’ (DeWitt et al., 2013b, p.1055). These are higher percentages than were reported in United States by Rudolph, 2014 (see section 3.5.2). Stephanie’s ‘big lot’ are those children who are not going to do science or use science in their future jobs. There is also an uncertain understanding in society about how many pupils should aspire to be in any of the groups (*Ibid.*), how many scientists are needed for the future of the economy or whether there is a finite number. Also depending on which research article is cited these numbers vary slightly (DeWitt et al, 2013a; Dewitt et al, 2013b). Yet the challenge in primary science is how to engage all groups and keep them with the teacher.

Stephanie's 'would be' scientists might need a Vision I approach (Roberts, 2007), but such a view of 'real scientists' and 'real science' tends to be based on the myth that scientists are a special class of people who are particularly endowed with superior mental abilities, exceptional problem-solving competence, and well-tuned scientific process skills that they use in an impartial pursuit of truth' (McGinn and Roth, 2004, p.104). This elitist vision may play a part in why, so few aspire to be scientists. Stephanie is concerned for the 'big bunch' who do not associate science as part of their future identity. She is also worried that a fact-based approach in primary science fails to include opportunities for identity transformation, (Carlone *et al.,* 2011), which the authors discuss as opportunities for those who are not currently interested in sciences to become engaged. This is important to Stephanie because she believes they will 'live and experience life because of science' and thinks they will be disadvantaged without a love of science. However, Stephanie believes that these learners should adopt some specific scientific attitudes.

7.3.2 Presuppositions of Informed science citizens:

Stephanie touches on scientific attitudes as she discusses the role that science plays in all pupils becoming informed and capable citizens. She is concerned that most researchers and those interested in primary science education have the wrong focus.

> I think the vast majority focus heavily on these few who will be the big scientists whereas I think my focus initially is on the other end those people who are going to live with science .. and if they don't appreciate … and love. And notice I use **love** not understand ... love the science aspect of the world, then they won't engage with ... life. So, you know, you get all the protests about ... wind turbines and solar farms and all of that kind of stuff and are they protesting ... sensibly? ... Or is it purely emotional because they don't want it in their own backyard - that kind of stuff? … I think it should be the former. They can still protest but they should have weighed up the scientific options ... which because they love … experiencing science, and because they are curious ... they can do.

Stephanie makes an important distinction between understanding and loving science. Stephanie has loved science since she found 'the strange thing' where everyday observations explained ideas and brought a sense of joy. Stephanie's emphasis is on science's capacity to solve problems and that the public should not to use personal standpoints until they have 'weighed up the scientific options.' This 'positivist view of the nature of science is common in science education' (Fensham, 2004, p.23) and could partly result from the way primary science developed, with a focus on practical and intellectual processes, reinforced by the way science advisers promoted one view of science. Reiss (2004) proposes that 'it is not too much of a caricature to state that science is seen by many as the way to truth', and that in this 'worldview' the advance of science involves scientists 'discovering eternal truths that exist independently of them and of the cultural context in which these discoveries are made' (Reiss, 2004, p.4). This approach can lead to a naive view that the laws are out there in nature and scientists just must find them (Schizas *et al.*, 2016). However, for Stephanie, the practical nature of science is vital because this is how she likes to learn:

> I enjoy experiencing things and if I was a kid I would enjoy experiencing, the thinking and finding out for myself through the practical side…. myself more so that if I am gaining it that way then that is what I want to do with the children

Learning for Stephanie involves experiencing things and this involves 'the thinking', and I wondered if this was like the view held by Dewey (1915) (see section 3.5.2). I had asked if science must be practical and, as can be seen in the response below, Stephanie was thinking whilst answering, and there were more pauses:

> …………. Not all the time………….. not all the time …no .. there is a time and a place.. sometimes its practical and sometimes it isn't … I mean we have these theoretical scientists, so they don't do it practically as in on their hands is it practical when they are thinking? … different kind of practical …. It is getting the balance right.. when does it have to be practical and when is it thinking?... and in some instances when is it simply being told …………..

The problem is what is practical? Was it still practical when the scientists are thinking? This is an interesting insight, and Stephanie proposes that thinking is practical, just a different type of practical, where I am not being told, I am thinking and working it out for myself. I pursued the statement 'and some instances when is it simply being told' and questioned what might be told and Stephanie's response was 'mmm …………………yes………………..don't know ………………because I try and avoid that bit.' However, this was not the only issue, as Stephanie identified that in her role that many schools no longer teach primary science, which will have a damaging impact on scientific literacy.

7.4 Wider policy influence: Why science is not taught in some schools.

Stephanie identified that some schools do not provide opportunities for the 'big bunch' as they teach little or no science. Stephanie placed the blame for this squarely on the requirements of other aspects of the curriculum, which are still regulated by government tests:

> [I]f you think about your groupings of children, in the first instance there is a literacy and numeracy issue for those children [the big group] and the schools have a massive focus tunnel vision, so you have to do literacy and numeracy only! Whereas if they set their literacy and numeracy within life and science is part of life, they [the children] get it .. So ... they [the teachers] are not doing anything about science, they put it under the table and even the literacy and numeracy does not come up that well.

This finding that teachers do not teach science is supported by the baseline research for the Wellcome Trust (Leonardi, *et al.,* 2017). Stephanie alluded to a huge debate which involves the very nature of education provision. A narrowing of the primary curriculum is evidenced by a range of research (Wiliam, 1992, Stobart, 2001; Tymms, 2004; Black and Wiliam, 1998 and House of Commons, 2008). This problem is ignored in many studies on teacher's subject knowledge which fail to address any contextual issues, such as curriculum time, resources, and pressure of other subjects. Therefore, factors which are very important in determining classroom behaviours become invisible (Van Aalderen-Smeets *et al.*, 2015). The CBI report *Tomorrow's World* (2015) addressed the issue of curriculum time and found that 'over 1 in 20 schools – at both KS1 and KS2 – provided less than one hour of science education a week' (CBI, 2015, p.14). The Wellcome Trust report suggested that weekly science was occurring but that more than half the schools taught science for less than two hours a week (Leonardi, et al., 2017, p.7). The CBI report also supports what Stephanie has seen in her work within a local authority: that science has lost its core status in schools:

> [T]he Wellcome Trust, the CBI and others believe that many primary schools now do not recognise science as a core subject, as they do with English and maths – and as such do not treat it as one … over half of those that we surveyed said that science had become less of a priority at primary school over the last five years. (CBI, 2015, p.14)

This loss of core status is not a new phenomenon and was identified by Stringer (2010a). It is also possible that science is still being taught but has become integrated into other subjects rather than being a stand-alone subject (Hollins and Reiss, 2016). The Ofsted science review, 'Maintaining Curiosity' (2013), identified the diminishing importance of science and acknowledged that, in over half of the schools that inspectors visited, the senior management team in primary schools no longer identified science as a priority. In 'Is the science the poor relation?', Cutler (2015) takes the debate back to teacher qualifications citing the CASE report (2014), that only 5% of teachers have a science degree, although The Royal Society (2010) identified that the data was inadequate, so it was difficult to know which qualifications were held. There are also discrepancies, with findings suggesting that those teachers who completed an undergraduate course had 'better subject knowledge than those who completed a PGCE' (Postnote, 2003, p.3), contrary to the view that higher level qualifications are linked with better subject knowledge. Stephanie took this debate into a different direction, discussing schools that were doing integrated project work, so science is occurring but not 'science science'.

> You get a cross curricular nature of work, like the old project work so if you do a topic on flight you do angels to cover your RE ….. it is a bit tentative… um.. you can think of even more stretched examples … um in order to get it in so do you just end up doing science science ….. or have you just ticking a box to say if we are doing something about chocolate if we melt some chocolate we have covered our science on reversible change but if you don't do other reversible changes you have not covered that ground at all by doing chocolate

Stephanie believes the context is important for the 'big group' who are going to live in a world controlled by science but who might find this subculture alien to their everyday life. Yet science teaching is often the transmission of this subculture, which for those that are going to do science and work with science is supportive (Aikenhead, 1996), but for the 'big group' is not. Stephanie believes a topic or cross curricular approach might support the big group to love science rather than them having to play Fatima's rules (Larson, 1995). Fatima was a student who identified that 'school science' was about rote learning and going through the motions. Aikenhead, in a study with First Nations People, identified that in order to learn science there were three options. The first is enculturation where science is accepted as the world view, something which has been discussed previously (see sections 1.2.5; 4.2.3). The second is assimilation, where science is at odds with pupils' own cultural beliefs but is adopted and becomes the dominant thinking process and how the world is explained. Or finally by playing Fatima's rules where the student accepts scientific knowledge in order to succeed in school, but science and scientific views play no part in their worldview. Stephanie identified the 'big group' as ones who struggled at reading and writing, who were not getting it but if the teachers 'set their literacy and numeracy within life and science is part of life, they [the children] get it.' Stephanie went on to explain:

> and I was in one [school] this morning … and it is quite incredible the turnaround in terms of how stuff is correctly and sensibly linked together well, not artificially .. um and therefore kids will be getting a lot out of it

For Stephanie the context is not the whole problem, and her transcript included the fear of teaching primary science.

7.4.1 Working with others: preventing the fear of science

This section examines how Stephanie sees her role working with others and passing on her skills, in the same way the adviser did when Stephanie first came to love science. Stephanie identifies the subject-laden side of science and previous experience in secondary science as being an important factor in 'the fear' of science for some primary teachers. She discusses her position on 'the fear' using a specific recent example: a teacher who is involved with the Primary Science Quality Mark (PSQM) whom Stephanie has been supporting. The PSQM is a system which allows primary schools to work towards and achieve recognition for the quality of their primary science: 'PSQM is an award scheme for UK primary schools. It requires the science subject leader (co-ordinator) in each school to reflect upon and develop practice over the course of one year, then upload a set of reflections and supporting evidence to the database to support their application' (Earle, 2014, p.216). Stephanie discusses how one teacher responded:

> [T]oo many teachers probably have not had that experience of that side of science. They've experienced this side and not done well there and therefore they become quite fearful and nervous of it … um .. but when you do have that breakthrough and they start to enjoy it as one of my PSQM schools this year, P.E. coordinator was told at the beginning of the year that you have to do the science subject leader job this year [Stephanie pulled scared face and slight 'argg' sound heard in tape] and then she suddenly discovered that the school had paid to do PSQM whispered 'God's truth … you know' as well this year, and in her submission that she just put in last night .. in section E it actually says. 'I am not going back to P.E., science is wonderful'.

Stephanie uses both context and 'cultural knowledge' (Gee, 2011, p.6) to convey meaning - setting 'that side of science' against when they've experienced this side: 'that side' is the non-practical, 'theory-laden', didactic transmission science or any aspect of science that is not practical (or thinking) in nature. This is a prime example of shared understanding where people leave things out or unsaid as they assume the listener will understand what they mean (Gee, 2011).

This teacher suggesting that 'science is wonderful' could be seen as an example of crossing an identity boundary where 'one chooses to be part of a group that has norms, practices, and values that may nudge one's personal action boundaries' (Carlone *et al.,* 2015, p. 1528). But whilst the idea of science identity is growing, it is worth remembering that is a concept that is 'slippery and difficult to operationalise in a way that provides solid methodological and analytical direction' (Carlone and Johnson, 2007, p.1189). The P.E. coordinator, who originally was reported to have said 'God's truth' when she found out she had been given the role of science lead and was sent on a PSQM course, also demonstrates that 'personal histories impact on an individual's willingness and ability to engage with particular Discourses' (Danielsson and Warrick, 2014a, p.107). Abrahão (2012, p.29) indicates that the 'narrator's perspective on the past reality is involved in any narration'. Stephanie was originally the P.E. coordinator who 'got science'. Out of the many hundreds of teachers with whom Stephanie has worked with very contrasting subject backgrounds, she chose to recount the story of a P.E. person**.** The teacher received the PSQM award and with this recognition is now able to enact the discourse of an effective primary science teacher who is 'not going back to P.E., science is wonderful'. Perhaps this is another example that indicates that Stephanie believes that identity can change, as it did in her own case with the support of others, and, when discussing PSQM, she said 'it is incredible that ... it kind of tingles..' describing the feel-good factor of enabling others to succeed.

7.4.2 Presuppositions: Conquering 'the fear'

Stephanie does not consider that teachers innately cannot teach primary science – 'they just have to change their attitudes and learn again':

> I think that they have ... they have learnt that… they have learnt the science by doing the science with the kids themselves so they have started to ... to ... Yep well they did not get it when they were at school and now they actually do it with kids, they themselves learn the stuff that they did not learn originally and they find that quite exciting ... when ... because I think that whenever you learn it does something to you exciting wise. And now they are learning science and they are excited, and they pass that excitement … back to the children and it is that big group again.

It was tempting to tidy this section, but this would hide the fact that a complex set of issues were being discussed. There are several separate elements discussed within this segment of the transcript. The first is a belief that effective science teaching requires teachers to undertake science with the children, becoming the ‘meddlers in the middle’, giving up the ‘sage on the stage’ approach (McWilliam, 2009) and changing their attitude. They are not enacting the traditional discourse of science teaching (Danielsson and Warrick, 2014b) but learning ‘the science by doing the science with the kids themselves’.

The second element is the excitement that Stephanie believes comes from learning new things - ‘whenever you learn it does something to you exciting wise’ so they are learning again. This excitement becomes the intrinsic motivation for the teachers to continue to learn alongside their pupils.

The final element is, in Stephanie’s view, the fact that all children are included – so it is ‘back to the children and it is that big group again’, those who are not going to be scientists or use science in their work.

The underlying debate revolves around what is quality teaching and how this influences pupils’ engagement in science (Timostsuk and Jaanila, 2015). For Stephanie quality teaching does not revolve around subject knowledge. However, the belief that the scientific knowledge of the teacher can be linked to better lessons is the dominant narrative and the traditional science teaching discourse. Stephanie indicated that there have been several approaches to deal with this perceived problem. One approach is to increase the teacher’s content knowledge, through the GCSE for teachers’ approach:

> [T]he big issue then is how do you deal with that … and is the dealing with that .. for want of a better term … a GCSE science course for teachers, right? Or is it …………. supporting and encouraging them and giving them the other aspect that they don’t have which is the confidence and the self-esteem to have a go and hence you get the P.E. person I just said about earlier in the sense that she had not been not on any science knowledge courses .. but … this year has been an incredible learning experience for her because … she had to, at the start, learn the science ... by working with kids, but actually - she actually has actually come round and she now wants to learn the science by working with the children, so it has been a bit of a switch.

Stephanie identifies the need to support teachers and change their behaviour and attitude towards science. Attitudes comprise cognitive, affective, and behavioural elements (Eagly and Chaiken, 1993; Van Aaldermeet-Smeet *et al.*, 2012). The attitudes that interest Stephanie are the 'attitudes towards science' comprising of values, feelings and thoughts - something that Newton and Newton (2011) called engagement. This engagement could occur within specific lessons or could be in science *per se*. Without the gesturing that accompanied it, the transcript alone is slightly confusing - Stephanie explains that initially, the P.E. teacher did not teach science at all, but after joining then PSQM she began to teach science. She was concentrating on getting the children engaged within a specific lesson; the focus was on enabling the children to develop their scientific knowledge. But as the process continued the PE teacher 'actually came round (sic) and she now wants to learn the science by working with the children, so it has been a bit of a switch.' The P.E teacher is now showing the inclination to respond in a positive way to a science-related activity. The P.E. teacher did not receive subject knowledge sessions, but Stephanie does identify with the issue of confidence and self-belief, demonstrating awareness of the narratives about primary science continuing in this community.

Stephanie does not accept that the issues will be solved by simply improving teachers' knowledge of science (Royal Society, 2012), as is revealed in the next part of the transcript:

> I don't know have you had had a chance to listen to any of the teachers doing the PSTT, [the primary science specialist course], have you come across any of them? I have come across a number of them and they will acknowledge that they need subject knowledge and they are getting it, subject knowledge and in certain aspects of science … they are doing it but **not** getting it - because of the way it is being presented - there are ways to acquire that knowledge and it is not back to GCSE style! And interestingly one charity on the physics side umm .. do things with teachers and they talk about 'having days with teachers and in the morning they get the teachers to take a topic and they get the teachers to GCSE science by lunch time' …………….. **do** they actually get them there? Or have they **'done'** GCSE science stuff with them, but these teachers are still not there yet.

Stephanie does not accept the GCSE by lunchtime approach has value as they are 'still not there yet' and the teachers Stephanie works with who have undertaken these activities still do not feel that they understand science. The Science subject specialist course (2013-14) was evaluated and Kudenko reported that teachers did not understand the relevance of the subject knowledge delivered: for example, one teacher reported 'Lots of very interesting knowledge and experiments. However uncertain of relevance back in School' (Kudenko, 2015, p. 8). The teachers valued the ideas that worked (Appleton, 2003) but could not see the relevance of the subject knowledge and how they would use it; so perhaps the traditional science discourse, that identified the teacher as authority and 'the pupils as recipients of knowledge' (Carlone et al. 2010, p. 943) is at fault.

Stephanie does envisage a link between confidence and subject knowledge, but this is not a causal one.

7.5 Biography and personal Style: Confidence, the chicken or the egg

Stephanie developed an understanding of primary science which was different to the science of her own education. She worked with the science adviser and was confident to say, 'I do not know'. During the interview the issue of teacher confidence was discussed as Stephanie considers that it is a chicken and egg situation:

> [M]mmm …. Is that … is that a chicken and egg situation in terms of which comes first? Umm and I suspect it is different for different people on which one comes first … ummm ….. because having ... having the confidence to - actually say to children **'sorry I don't know the answer to that one - but I do know how we can go about finding it out ….'** is remarkable when teachers do it and taking that approach - and it works .... so in that sense you need to have the confidence to ... as long as you have the confidence it will work … if you have not got that kind of confidence then in a sense you need the subject knowledge - strong .. so, which one have you got…

Stephanie asserts that confidence is having the self-assurance to say, 'I don't know - how we can go about finding it out,' adopting a 'meddler' role. Stephanie is aware that for some teachers the traditional teacher discourse is too influential and in such a case they need strong subject knowledge – strong, because they are left with the role of the 'sage' and having to teach the children science facts. Stephanie also has reservations about such a knowledge-centred approach, because whilst a sage might have subject knowledge and understanding this will not guarantee they can develop learning:

> I go back to my A Level maths days and the incredible mathematician guy who just could not get it across to people and could not understand why people could not get it ….. umm ... whereas probably the best maths teacher I have ever come across, two of them were actually in the school I taught in … umm who nearly had to give up teaching because they had not got GCSE maths but they understood and appreciated the issues kids had in trying to learn maths because they had gone through it as well and therefore they could put it in a different way … so in that sense confidence but not the knowledge.

This differs from the notion that teachers with subject knowledge will know what and how to teach. Stephanie appreciates that teaching involves empathy to understand what it feels like not to know. Subject knowledge is not helpful if the teacher cannot communicate their understanding or if the learner cannot identify with the worldview that is being presented. Stephanie's definition of confidence is having the courage to admit to not knowing and to learn alongside the children.

Although research from English speaking countries continues to link teachers' lack of science subject knowledge with confidence (RSC, 2014) this identified deficit of teacher knowledge was discussed in 'Maintaining Curiosity' where '[t]eachers' subject knowledge was good or outstanding in three quarters of the primary schools visited, and adequate in the rest' (Ofsted, 2013, section 11): There is a disconnect between this Ofsted finding where no science teaching was judged to be poor and the views articulated within the dominant narrative. Teaching science is occurring, and Stephanie went on to discuss her presuppositions about teaching science and how children learn.

7.6. Presuppositions: how learners learn

Stephanie's mode of teaching is very different from a traditional didactic model of education and is about challenging learners and not providing answers. Stephanie suggests that:

> Science is finding out and then exploring what I or an individual currently thinks or understands about something … and challenging that view with an activity or a question that makes them question that thought … they may still end up with the same thought and the same understanding at the end of it - or they may have shifted a little bit or a big bit their thinking and understanding ……… from the child who thinks that a slug is simply a snail without its shell, who spends all day watching a tank of snails to see when a snail will come out of its shell and leave it alone - and therefore be called a slug … At the end of the day you think – surely you know a slug and snail is different? ….
>
> For the child to say 'But maybe we have not given them enough time for them to come out. So, can I spend tomorrow watching it?'
>
> 'No, no, we've got other stuff to do!' ……
>
> I think by the end of the day he was having it on - and I think he had come to an understanding that slugs and snails were two different organisms.

This section of the interview was performed with voices and action and I could visualise the child's interest in snails leaving their shells and becoming slugs, if given enough time. This misconception is like Aristotle's idea of spontaneous generation; it is only that science now has a different answer for how this happens. Stephanie considers the teacher's role is to be 'actively involved in assembling and dis-assembling knowledge and cultural products' (McWilliam, 2009, p.288). Stephanie tells teachers 'If I do it, will you actually learn it … no, you need to do it in order to muscle learn it.. as it were'. The idea that the brain is a muscle and the more you use it the better it becomes, suggests that all can learn if science is about first-hand experiences. The idea of a brain as muscle is controversial but again recognises the presence of narratives of brain-based theory in education. Stephanie believes learning by questioning is important 'because it hurts their brain because you challenge them all the time umm it's kind of um … one kid asked me long ago does everything have to be a question with you? Do you ever answer the questions?' Stephanie considers her role to help to assemble new science knowledge whilst dis-assembling the old everyday knowledge, and it struck me that there was something of Plato's *Meno* in her approach.

The section on slugs and snails demonstrates the difficulty of changing everyday ideas to scientific ones. Stephanie suggests that learners obtain the correct science by not telling, but by making them active in a ‘hurts their brain’ way. Stephanie considers that questioning approach was how she ‘learnt stuff’:

> Umm because by **throwing it back** at them all the time it makes them stop and think and **question themselves** … what they thought they understood … because actually **I think** even though I did not know the term at the time … and therefore that kind of approach .. I think that is the way I’ve learnt stuff.

Stephanie’s presuppositions about science as a way of finding out about the world result in her belief that children learn by being challenged, that real knowledge cannot be given, and the role of the teacher requires empathy and questioning.

7.7. Summary

Stephanie is successful in her field. She initially came to science subject leadership in a convoluted way and recognition as a science leader has been important. Over thirty years she has learnt that science requires teachers to develop the courage to learn alongside the children and that confidence is the power to admit to not knowing. Stephanie does not embrace a simplistic subject knowledge = confidence framework but instead promotes learning alongside the children as the answer.

Underpinning her view of science is a belief that it is through the processes of science that science knowledge is gained. Stephanie suggests that science education in primary schools has the responsibility to enable the ‘big bunch’ of learners to ‘come to love science’ in order that they make the correct choices later in their lives about scientific concerns such as wind farms and genetic modification. One way to support the ‘big group’ is to set science in context.

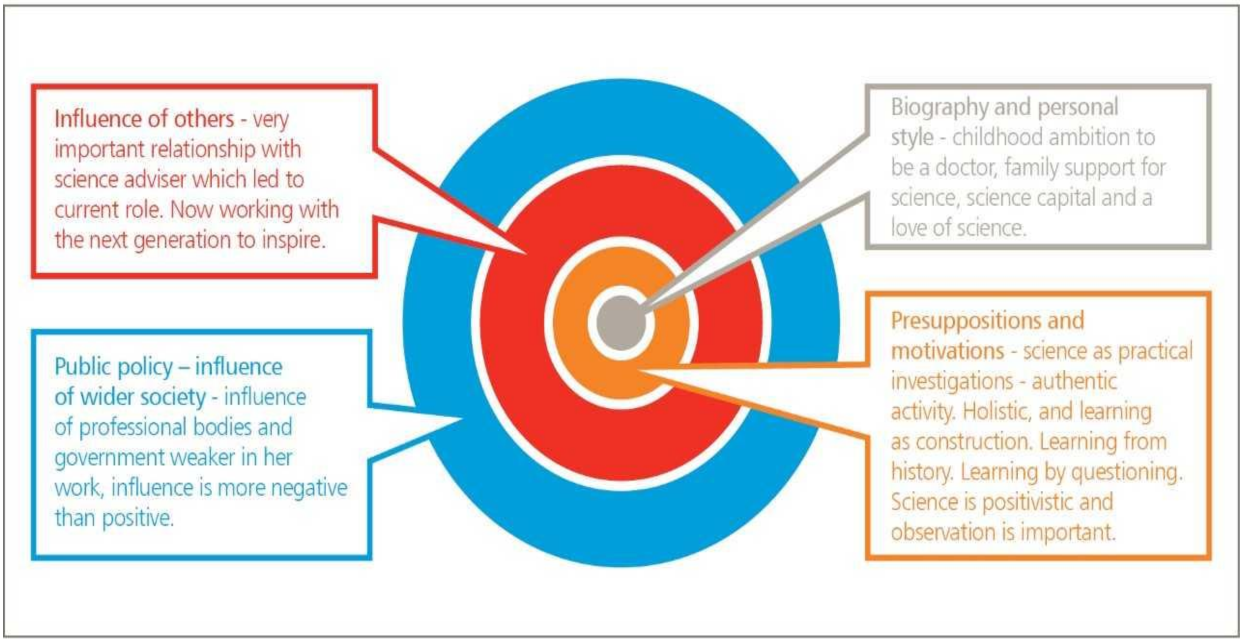

Figure 8: Stephanie’s sphere of knowledge creation

I identified with much of Stephanie’s story and until recently would have accepted nearly all aspects of her worldview. Working with her made me question my positivistic ideas and, as we discussed the snail example, I began also to question my understanding of teaching approaches. Her ‘big group’ who are not assimilated or encultured into science and therefore do not have a science view had an impact upon my thinking. In Stephanie’s’ example these children had poor literacy and maths skills and attended schools where science was not taught. Stephanie’s recommendation was by teachers adopting a cross-curricular approach the school could make science part of the children’s world thus providing a context for these learners. Stephanie’s approach does not exclude any learners but identifies that the big group will not work with science or become a scientist. She holds a view that all can come to love science. This biography made me think carefully about the courage required by teachers to adopt a ’learn alongside the children’ approach where together they develop an understanding of science.

Chapter 8: Justine - The child as a scientist

In this biographical chapter, Justine shared what is important about primary science and what she considers successful primary science lessons should contain. Justine has been involved in primary science for at least three decades and for the last decade she has held several nationally influential roles. Justine is warm and friendly, good company, and well respected within the primary science community.

8.1. Introducing Justine

Justine has been involved in science education in a range of roles and, at the time of the interviews, in her work with the Department for Education, was supporting the government with aspects of primary science. As the director of several important science projects, Justine requested anonymity as there were things, she wanted to say that she felt could be problematic in her position. I have known Justine professionally for more than a decade and have worked with her on a few projects. Throughout the interview a shared understanding was represented by unfinished sentences, the repeated use of the term 'you know' and education jargon (Gee, 2011). It was the jargon and language use such as 'pin learning on to' that the fellow researchers who read the transcripts struggled with, although coherent to both I and Justine.

Justine's language throughout the interview was informal and frequently she references many influential boards, committees, or people. She also whispered at times, which is not apparent in the transcript which gave the interview a conspiratorial nature. Justine also used her hands when talking. She did not change her voice to signify what others have said but used reported speech. Again, I have used the SKC (figure 4) in order to work with the interviews with Justine.

8.2 Biography: Becoming a teacher

Unlike other participants, who talked about their childhood love of science, Justine did not develop a love of science at school and she expresses some concerns about this. When asked how she came to be where she is now, she started with the word '**right',** almost as though she needed to get the non-science aspect out at the start of the interview: '**Right**, I did an English degree, always fancied being a primary teacher having done work in a play scheme and stuff through my degree … ur .. also, very good strong positive memories of primary education'.

Although Justine had positive memories of primary school, they did not form an important aspect of the interview; in fact, even when questioned about science and primary school, Justine could only remember a science book:

> I do remember that there was a book …. and I can remember dying to have a go at some of the activities in it … I don't know how you got to do them but I never did ... because one of them was standing on your head could you drink and I thought it looked like such a fun thing to try - but I never … got to do it, I did at home but (laughs) no I did not do any as far as I am concerned I was at school in the 60s in primary school and we just did a lot of topic.

Justine knew she wanted to be a primary teacher and was keen on poetry. Her view of teaching was also coloured by the early years of her teaching, the issues of teacher status and the state of the school system (Gillard, 1987). Justine has strong beliefs about children and learning which were apparent from the start of the interview. Justine did not study secondary science subjects because science subjects were not compulsory at O' Level. She took this decision very early one that the sciences held no interest or significance to her; she had some of the characteristic of student who Costa would classify as an 'I don't know (Costa, 1995, p.322) regarding their acceptance of science:

> [S]o therefore my first biology lesson was about an amoeba, a one celled organism I did not know about … I had nothing to build on … and suddenly I was dealing with this abstract thing that I did not know what it was … and in chemistry we were into the periodic table and I did not know, and I did not understand about materials and their properties - with physics it was forces …. but you know no-one had talked to me about pushes and pulls.

Justine, like many, favoured the humanities rather than science (Kragh, 1998) and studied English at university. The English degree was followed by a PGCE, at 'a good institution' but at what she considered was 'a bad time when it was teacher action when we were probably at the worst end of post-Plowden pre-National Curriculum hole'. Describing the Plowden report as 'the worst end of pre-National Curriculum hole' was unexpected, as there are elements of the Plowden report that mirror some of Justine's core views of education - for example, 'at the heart of the educational process lies the child' (Plowden, 1967, p.7). Whilst the positive influence of Plowden can be found in policy papers written after the National Curriculum (Gillard, 1987), it was the William Tyndale affair that brought suspicion that primary education needed to be reformed and a notion that the Plowden report and discovery learning were synonymous.

Justine's comment about her teacher training and its promotion of a particular approach - 'I did not really do anything that did not involve playing …. make a board game type of thing' - is something that Ryan (2003) would still recognise today. Justine could not remember any science input in her PGCE course. Justine's early teaching was in London at a time of teacher strikes, and because there were no staff meetings, parents' meetings, or the other aspects of school administration, Justine said 'I had a really nice couple of years having fun with a group of children', which suggests a very unregulated system, but one which provided her with skills she was later to draw upon, although she did not teach any science.

Justine moved from the metropolitan multicultural schools of London to the suburbs after 'only a few years' and began to work in an advisory role, supporting multicultural education. She provided a simple summary, 'did a bit of multicultural support far too early, I was not ready for it in any way, to be working with teachers when I had no real experience really'. Justine then had time away from teaching to raise her family and returned to work in a local primary school part-time. The National Curriculum became statutory during her time away from teaching, and when she returned, she took responsibility for technology, as she had experience of this subject when working in London. This is the part of the interview where science was first mentioned, and Justine said she found 'this science is interesting and sort of … getting interested in that'. Justine ran projects because, as a part-time teacher, she had more flexibility than a full-time class teacher. Through these projects Justine was nominated for an engineering award and this led to leaving her school and working in an organisation that provided education services to primary schools.

8.2.1 Working with others

Justine's new role was in an advisory capacity working with schools creating workshops for serving teachers and running courses for Initial Teacher Education (ITE). Justine worked with 'an influential mentor' who was significant in her subsequent move to full-time consultancy, and her continued involvement with both initial and continuing professional development. Justine indicates that this time was instrumental in her later career role - 'she [The Mentor] was developing workshops to be used in ITE about …. Plants.. I worked with her for a couple of years on an ad hoc basic, learnt masses.' This experience eventually led to the role she now undertakes.

Justine's personal style and biography demonstrates something that is clear throughout her career: she is hard working and adaptive. Although Justine showed no affinity for science at school, her mentor became her tour guide (Aikenhead, 1996) and helped her developed her science world view. Justine enjoys engaging children in active learning; she is a quick learner and flexible in both the roles and activities she is willing to undertake, as this segment from the transcript demonstrates: 'I did something on building greenhouses with children … model green houses and grew things in them …. And we built a wind instrument - a big organ with a local engineering company … then something with light .. I thought I don't know anything about this really so let's work it out'. Justine wanted to work at the university so enrolled on a master's course.

Justine acknowledges the important role that others have played in her professional development, supporting both science knowledge and pedagogy: 'I have learnt it [Science] as I go and I have thought about it hard about what those big ideas are … people I work with through my work here [University].... just have taught me lots.' *The Big Ideas* (Harlen, 2015) is a publication that has been influential on science education in ITE. At its heart is the notion that there are ten principle underlying 'big ideas' of knowledge which the authors suggest all students should know in order to help them understand and make informed decisions about science in their life. It was written by scientists, engineers and science educators.

Justine has undertaken a range of roles, including working part-time for a Local Authority, supporting both science and technology until she took up an important role within primary science education, the role she currently holds. She then dropped the bombshell that she was 'waiting to be found out … with no background in science whatsoever'. This part of the interview was whispered, even though she was in her place of work and there was no-one else about. This statement raised the question of who she felt might judge her, and if a science background was more important than the competences she demonstrated daily as part of her role? It also raises a question about the influence of historical views of primary teachers and subject knowledge on education policy.

8.2.2 The public policy: the outer ring of knowledge creation

One of the roles that Justine undertakes is to provide advice for those making choices and decisions about important aspects of primary science education policy. I have never questioned Justine's background having only been aware of her professional life. I was therefore very surprised when she shared her concerns and worries about being 'outed' as a non-scientist' [her words]. This is something she expanded upon when asked why she felt exposed:

> but because of this job working here, in the university, in the network and all the other things that I do with primary science - I am often the only non-scientist around a table … now I sit on boards for advising and I am the only primary person and I know I am the only one there without a science background …. And sometimes I feel a bit … exposed'.

Despite this apparent frailty, Justine is very clear about what is good primary science, as will become clearer later in this chapter. She also identifies the sort of experiences some children receive and aspects of practice with which she does not agree. The teaching Justine has undertaken has shaped her and has helped her create herself. However, as exemplified by her worry of discovery, the situational influences impinge upon her substantial self (Nias, 1989). This confirms that no narrative is based only in the present, as the personal perceptions of the past shape the present (Polkinghorne, 1988; Bourdieu, 1990; Bruner, 1990). I felt this was an area that required greater clarification, particularly as she appears to worry about being 'exposed' - not because someone will ask to see her science GCSE certificates but 'because I think I will say something ... I will just not know the answer and I will make some crass statement about something … that everybody knows'.

As discussed previously, the primary science dominant narrative concerns teachers providing canonical knowledge. This 'Traditional Science Teaching Discourse,' evoking the teacher as the knowledge deliverer, is powerful; indeed, Smith (2005) and Carlone *et al.* (2010) go so far as to state that 'the Traditional Schooling Discourse never goes away' (p.994). This is something that is clear in Justine's concern about being 'exposed'. The language she uses suggests that the wider circle, the public policy, influences her view of herself and her belief that there are things in science that 'everyone knows'. If the guardians of canonical knowledge can make an influential science educator whisper, it is unsurprising that this common view influences primary teachers in classrooms across the land. This position was expressed by the Teacher Training Agency (TTA): 'Secure subject knowledge enables teachers to judge how ideas and concepts can be broken down and sequenced logically so they can support pupils' learning' (TTA, 2002, p.18). Although research suggested that science qualifications were not accurate predictors of either relevant knowledge or teaching competence (Jarvis and Cavendish, 1994), the TTA asserted that 'to do this confidently and effectively teachers need a high level of subject knowledge and understanding relevant to the pupils' curriculum' (TTA, 2002; p.18). As previously identified, confidence is a complex construct, not in a simplistic cause and effect relationship and effective teaching requires more than subject knowledge. Justine is highly regarded but is anxious that she will say something crass about the science that she believes everyone knows.

Justine gained a love of science after formal education and her inclusive science Vision II stance includes child as explainer and everyday coping (Roberts, 2007), but this is sometimes problematic for her as some of her work is funded by those who have a Vision I approach. She explains:

> I know that most of my work is funded by X [Justine names a group] … and those people want scientists for the economic prosperity of the country and I get that argument - but I want everybody to be scientifically literate. I don't think that I grew up scientifically literate it was not part of my education.

Justine's work involves her with debates about education from a range of perspectives, and all these influences her vision for science, which is one where science looks outside towards society, and this interpretation influences what she believes is essential. One of these debates particularly stuck in her mind:

> I was at the Institute for [names a professional organisation]… on their X board and their dilemma is - how do we make .. we want to keep the cachet of [the subject] being a hard thing and worthwhile to do and it opens up a lot of possibilities because [studying this subject] will teach you how to think - and all of this … and then also that it is not …. they sort of don't want it to be elitist.

Justine discussed this apparently confused vision by those who are the guardians of a subject - the Vision I cachet of elitist science. Where there is a struggle between the inner-looking view of a subject that is hard, worthwhile, and for the few, contrasted with the outer needs of society and for science to appeal and be understood by the many. It is not surprising therefore that Justine sees science policy as being conflicted.

Justine's home background was not scientific, and her own children have shown no interest in science, regardless of her role or her espoused position on teaching science. However, she mentioned that one of her extended family members was going to study physics, which she explains by suggesting he has 'a real desire to be clever you know I think he is driven by the "I want to be clever and it's a hard thing to do"'. This could be understood as an elitist view, but there is something problematic about the struggle between an 'elite and difficult' subject and the need to increase the numbers and types of students that take such a subject. The conflict concerns whether both visions can be taught by the same curriculum, with Justine being convinced that it is possible by providing access to meaningful 'significant events'. This and other presuppositions are now examined.

8.3. Presuppositions: Visions of science

The varied visions of science that Justine holds are discussed in this section. There are several threads: the idea of learning being about significant moments; that learning science should not be about 'wow' moments; and the importance of science in the everyday world. The term 'wow' was previously used by Ben, and to explain this term, picture a child with an open mouth mouthing 'wow' as they watch something amazing. Justine's overwhelming belief is about the central role of the learner (self as explainer) and their personal interest in learning. Britzman's view of learning to teach exemplifies Justine's development of the teacher educator she has become:

> Learning to teach — like teaching itself — is always the process of becoming: a time of formation and transformation, of scrutiny into what one is doing, and who one can become. (Britzman, 1991, p.8)

Justine is still developing herself and her understanding of primary science through the various roles and the people she works with. Her 'becoming' (*ibid*) is focused heavily on the side of children, their interests, and skill development, in the continuum between science for society and science for the individual (Eisner and Vallance, 1974, cited in Pollard and Tann, 1993). This is a complex set of ideas and the belief that science is something for all children, which was expressed as part of the Justine's personal understanding of the scientific literacy argument, is the starting point.

The debate about why so many children should study science, when few will go onto to become a scientist, has been discussed. Using Roberts' (2007) categorisation Justine is clear her emphasis is Vision II – [the person she is discussing is a well-known public figure X and his book XX was about science. X is a broadcaster]:

> I did some interesting work last year with X, you know the book he wrote about an XX and I had to do some work with him on .. and I said why do we want children to do science, and he said 'because the *Daily Mail* gives crap headlines' and it's true and there is a bit of me feels that at one level I want every adult, every citizen, to say actually 'that does not make sense' or just you know – 'why did they say that?' and 'where is the data to back that up?' and 'was that the right question to ask in the beginning?'

Justine wants every citizen to ask questions concerning the nature of scientific evidence, and about the nature of science, rather than just the facts of science. This 'everyday coping' (Roberts 2007) provides the reasoning skills for questioning science in everyday life. Vision I contains the curriculum emphasis on the foundational knowledge of science, science as the correct explanation and the belief that there is a structure to science (Roberts, 1982).Within this Vision I perspective is a wider position on the role of teaching science, all about persuading students of the validity of a scientific world-view (Duschl and Osborn, 2002). Justine embraces this validity of science unquestioning:

> I think we get such awful messages and the stuff you hear on Radio 4 every morning 'our survey shows …' **No,** it doesn't! The survey may suggest a link, but it is not proving anything. So, it is that sort of thing …. I just don't think we are very good in this country at about talking about science very effectively and accurately.

There are different forms of reporting science in the media and the way each discusses and presents scientific breakthroughs; however, there is the link between Justine's personal beliefs and how these influences her interpretation of the curriculum. Justine's 'science for all' vision is at odds with the research findings that science is 'unthinkable' for many (Archer *et al.,* 2012; Carlone *et al.,* 2015). What is exemplified is that when a vision is held, it colours the world.

Justine's presuppositions are that science is about facts but just as important is how children gain access to these facts. This is part of Justine's larger vision of science, and was clear from the first interview, especially when she explained why she became a primary teacher: 'I had a very positive belief that it should be about significant events that a child would remember, that would give them …. things to pin learning onto but also that they would remember well, so I had a very strong view about significant moments.'

8.3.1 Presuppositions: Significant moments

For Justine, 'significant moments' and 'significant events' are how children learn … and how children make sense of their world.' Justine's role brings her into contact with practising scientists as well as policy makers. Justine's literary background is revealed when she uses words to paint a picture of the child as a scientist on a beach in the summer.

'You can just hear children busy. I find that absolutely lovely and the fact that on a beach there is more space and more time than they probably would have, and you just hear and watch them .... being scientists; I find that absolutely glorious … I remember talking to the guy who discovered DNA fingerprinting ... and he said being a scientist means being a perpetual child …… just …. noticing ..... and answering questions and being interested in the world.'

The picture of the child as an 'explorer' or 'the child as scientist', is encapsulated by Justine's visualisation of the child on the beach and is an illustration of the view that there is little difference between scientists and children (Gopnik, 1996) (see section 4.3.2). This child-led learning is something that Duschl and Osborne (2002) suggested, almost 100 years after John Dewey, was still not occurring in classrooms. Justine's belief that learning should be led from the child reinforces the notion that there is a common thread of a child-centred approach to learning and to primary science teaching in general (Russell *et al.*, 1992). This child-led focus is expressed by Justine and consists of 'first–hand' and 'true' experiences, but there is, in addition, a specific role for the teacher, which is clear when she discussed her role as editor for a commercial science scheme of work that is currently used in many primary schools in England:

> I have a real passion about first-hand experience and children learning through the real world … and having real ... true experiences rather than …. I was just editing some work just now actually - you know about earthworms and my feelings about four year olds and earthworms it should be whatever they think, whatever they notice, whatever they see and I don't want to force them to look and see them as this sort of creature, before they have worked out what sort of creature they might be. So, I feel very passionate about early years experiencing the whole world fully through all their senses, rather than narrowing them down to a sort of 'this is the bit you need to know' … so that has probably had quite an influence on me.

Although Justine is discussing this activity with earthworms is for young children, her desire is for effective science, at all ages, to be to be led by first-hand practical experience and this will be explored with further examples. Justine's interpretation of the nature of science is composed of a set of necessary and 'sufficient conditions' (Matthews, 1989; 1994) which includes the child as the constructor of their knowledge. The author of the curriculum material that Justine was editing had a clear epistemic outcome for their work - earthworms are animals and they move, eat, etc., but they are not the same as other animals. As a result, the author had written the task to direct the children, through a series of prescribed teacher questions: to learn that earthworms are invertebrates; they do not have limbs or a skeleton; that they are living; and they employ all the life processes. In my experience, having written for several publishers, commissioners of primary science curriculum materials generally require curriculum support to be prescriptive because they believe that teachers, who are the end users of the material, might not understand effective science teaching without this level of direction. This is just one of the downsides of the dominant narrative that suggests primary teachers have no science subject knowledge and is also another way in which a particular interpretation of the nature of science is perpetuated in primary classrooms. This teacher direction of children aims to build the child's foundation bricks (figure 2) in a set way. Yet Justine does not want the child to have their science learning prescribed in such a way - she does not 'want to force them to look and see them as this sort of creature'. Justine's view was further expanded upon when she was asked to describe a good lesson she had seen:

> I was at a school in Croydon it was in the middle of a very urban bit … and ……. on …. the second floor of this old building. All of the children had been out on the train to a meadow a sort of common … and … and … the teacher said to me some of these children have never been - they did not understand what the countryside was … there wasn't a shop a gift shop and a ... you just went and there was all this space and stuff in it and they were really overwhelmed by that. They had done some really nice surveying of what they had seen and found and everything and these were the follow up lessons.

Justine mentions the importance of space, of science activities linked directly to the children's world but also that science provides opportunities that these children have never experienced. In order to get a clearer insight into the processes and why effective learning in science is not just hands-on learning, Feldman's (1987) construct of the epistemic and ontic aspects of cognition provides a valuable gloss on Justine's narration. The epistemic aspect of cognition, by which Feldman means the way the world, is understood - the mental acts - are separated from the way the task is presented. How the task is presented provides the context, or the content of the task, and is something Feldman termed the 'ontic aspect' (1987, p.132).

The epistemic knowledge to be learnt was within the prescription of the National Curriculum and was focused on the parts of plants. The ontic aspect concerns science being in the real world, where there is space and materials (Feldman, 1987). The lesson then continued in the classroom:

> [T]he children were doing plant dissection just your general plant dissection but there were masses of it and they were all doing it and when they had done one, they could do another one and compare it. They were recording them and then they made one …. so, the teacher just gave them loads of stuff and told them to go and make their own flower ….. it was just - you know - it worked it was then demonstrating we put this in context we have seen all these flowers - we saw there were lots of insects round them now we are having a look to see what the different bits are, the teacher was filling in with some 'what do you think is

going on here?' 'What do these different bits do?' So, we were getting the vocabulary and the names for everything and then they made one so it was a way of expressing …. showing their understanding- it was just nice.

The key features were that all the children were undertaking the dissection; that it was child-led; and placed in context. The ontic element that Justine values was demonstrated, the teachers had brought 'masses of it' [lots of plants and art materials] - bringing the real world within the classroom and the teacher supported learning by asking open questions. The children turned their understanding of flower parts from practical examples, through dissection to model making, into increasingly abstract ideas; it was not just one flower but the structure of flowers in general. At the end of these successful lessons the ontic aspect can then be 'dumped' (Feldman, 1987, p. 137) by the child, resulting in the epistemic knowledge of both flower parts and their functions being established. The children are able to accept the scientific view of plants rather than how they saw them initially; the real world is 'dumped' and the scientific model of all plants established. These children concreted this understanding by making a flower, thus linking their developing epistemic knowledge into a different context which then allowed them to express their understanding and show that the new information has now become old (Feldman, 1987). This process develops knowledge of plants and is building the children's horizontal bricks (figure 2)

Through the comparisons and building models, the children used the everyday experiences to learn the scientific concept of the anatomy of plants. The importance of each part must be developed before reasoning can take place, but together these processes work in tandem, so that scientific understanding is built (Feldman, 1987). It is worth contrasting this with an activity where the children enjoyed the activity, but in Justine's view there was no possibility of science learning or 'ontic dumping' (*ibid*):

> They were doing air resistance … the teacher had obviously spent ages .. hours making parachutes beforehand there were all bits of paper with wool on each corner and she talked endlessly to the children about that they were going to do … the children were gagging to get in at them but couldn't because they had to sit and listen for ages about the fact they were going to use these parachutes and then they had to work out how to make it a fair-test and then they talked it all through endlessly and by the time they were actually going to chuck them around they were just beside themselves with excitement and really very little understanding about …. What was happening .. or … what they were doing .. they were just .. it was all a bit …. It was just a bit pointless really .. because the children were just chucking parachutes around by the end.

The lesson was well prepared, the teacher had 'spent ages .. hours making the parachutes' and the teacher was happy to teach a practical lesson in an area of the science curriculum that is thought to be difficult (Russell *et al.*, 1992). Justine does not comment on the teacher's lack of subject knowledge, only pedagogical issues (Shulman, 1986). For Justine it is the context, the investigative content and that the teacher 'talked endlessly' that was problematic. So 'the children were gagging' but the science learning was lost in excitement and there was very little understanding about what they were doing resulting in few cognitive processes. It was the teacher rather than the children asking the questions, which generally results in enquiry being 'circumscribed and controlled by the teacher' (Duschl and Osborne, 2002, p.45). The talk in the classroom was controlled and authoritarian (Mercer, Dawes and Kleine Staarman, 2009), focused on talking about the fair test with little opportunity for dialogic talk focused upon learning about forces. There is no comparison or any pattern seeking that would lead to anything other than 'chucking parachutes around'.

When I asked Justine what she would have done differently she responded: 'if the teacher had said at the beginning here are some parachutes 'let's see what happens to them?'…. and then gone this other way in - you would have got to a fair test beautifully if that was what you were after.' The ontic aspect could have been developed using parachutes of different sizes, asking questions such as 'what do you notice?' before moving the children into more structured activities using questions like 'what happens as the parachute gets bigger?' Justine suggested that the teacher could have used the same parachutes but allowed the children to 'play' and discover what happened to parachutes of dissimilar sizes. This approach could have promoted cognitive development with the teacher focusing these learners on what they noticed and how this linked to air resistance, building their blocks of knowledge. Justine suggests that starting with exploration would also have allowed the teacher to access their understanding, and then to provide some much-needed structure for the 'throwing of parachutes'. Questioning the children about the patterns could have occurred rather than undertaking a circumscribed and controlled activity, which although understood by the adult, was lost on the children.

8.3.2 Presupposition: Science in everyday life

Justine uses colourful and evocative language, painting a picture of what is there, what is important, and why teachers need to bring the learners into the world that science has created. Justine holds a realist view of a world fashioned through empirical means. Justine is immersed in science and can see science in all aspects of her everyday life, as her interest in builders demonstrates:

> I have had builders in my house for the last three months and I keep saying to them gosh everything you do is scientific, and it is all about materials and structures and how things move and actually that .. the basis of that is children understanding that different materials do … have different properties and are useful to do different things that different things will move in different ways according to the forces that act upon them and … and I find all of that understanding *the big idea* at the base of that really exciting and interesting and so I just think it is about helping children to recognise that … because I think they are interested in the world.

Justine relates a view that *the big ideas* (Harlen *et al.*, 2015) are needed in order to understand the world - in this case the world of materials and forces - and if the children have these ideas then they can access this 'interesting' world. This is a common viewpoint according to Ziman (1978): 'for most people science is the process of searching in which the facts of nature are discovered' (1978, p.70). This belief underpins Justine's life, including the builders, who are told 'gosh everything you do is scientific' and, in a later interview, she recounts sitting in her car with her daughter in traffic because of a new road building scheme:

> [I]t's such a massive project it's going to take a year over a year to build those roads and keep it going and I said [to her daughter] it's all engineers doing that isn't it and that is all underpinned by science and as people drive through that do they think that or do they just think it will happen … everyday people are making decisions in that process based upon materials and structures and forces and … and how they all work together and planning it in a way that a scientist would in terms of 'if this' and 'then this' and .. I find that absolutely fascinating, but I don't think we interact with it enough in our daily lives.

Justine's use of the words 'and planning it in a way that a scientist would' is part of her core belief system that science explains life and is central to how the world works. She selects words such as 'if this' and 'then this', which are part of the cause and effect model of science and reinforces the point that Justine finds science fascinating. She is at a loss to understand that when other people drive through this road junction, they take its development for granted and are not thinking about why and how this work is happening. Wolpert (2000) would argue this is not science but instead is technology and this confusion is part of the problem with the public understanding of science. This belief that science explains everyday life is also contrary to the view 'that most students will not deconstruct what they learn in school, to reconstruct it in a way that is useful to them in everyday life' (Aikenhead, 2006. p.30). Justine says she did not learn this science at school but taught herself later in life and is demonstrating that she has created a science identity that was previously absent.

Aikenhead' s claim is a sad indictment of science education, in that it suggests school science and real life have little congruence, but this perspective is supported by research which suggests students end up playing Fatima's rules (Larson, 1995). Justine's own children all played Fatima's rules: 'They all got science GCSEs none of them taken science any further forward, because they were products of that system where they just did it, learnt it, forgot it. The school taught it well they all got good grades.'

If all of Justine's four children did not want to continue to study science, did the school teach science effectively? Perhaps the Royal Society was correct when reporting that 'teaching to the test together with its associated fact-based approach to learning, misrepresents how science works' (2010, p.83). This approach suggests that teaching the pupils and the teachers to play Fatima's rules, where, as a result, the pupils do not wish to be assimilated into a tradition of science, is pointless: pointless in terms of the pipeline, but also pointless in terms of the endogenous (OCED, 2000) opportunities that science provides for learning. For Justine, her everyday life is structured by a scientific worldview, and as a result her observations are undertaken within this framework. The outcomes contribute to the form of self she accepts and sponsors a specific version of the world (Bruner, 1996).

Justine's realist approach is based on a need for the learners to make sense of the world using scientific tools of thought. Science for Justine is all about science's capacity to make sense of her world:

> I love the sort of making sense of the world bit about it and I love the way it makes sense for children and I love that whole rational approach of …. we wonder why or how or what, and we look for evidence and we satisfy that curiosity for knowledge and that bit at the front of the National Curriculum and I just find all that immensely satisfying, and I think it's a crucial thing for children to do.

There is comfort in this view, how the rationality of science is built upon the ideas of the fundamental permanency and regularity of the world. It is suggested that science should be easy for primary children to understand 'because almost all the children were prepared for it before they started school, namely they could observe things and orally report with accuracy what they saw' (Fensham, 1988, p.15). The perspective that it is possible to attain faithful knowledge of the material world is part of the reality of empirical science and is one which I have previously challenged [see Chapter 1]. It could be argued that the scientific picture of the world is not an illusion, as both scientists and children use the same principles to build knowledge (Gopnik, 1996) and that science is a natural experience for young children because it is undertaken using the sensorimotor skills of observation, experimentation, pattern seeking. Yet as science becomes more advanced the observations have a point of view in mind and use a process that Bruner called 'live science making' (1996, p.127) which is narrative in nature and uses metaphors and fables to help create understanding of our models of the world. Justine has a 'nature-out there' (Bruner, 1996, p. 126) viewpoint where she says, 'I love the way it makes sense for children' and in this version the children are constructing a theoretical world, that is reliable and worthy of belief. So, realism is accepted and develops into a much wider picture of a 'rational approach' to the world created by science.

The fact that science has a predictive element, the 'we wonder why or how or what', also plays a significant role in this belief in science. How could science not be true when 'we wonder ….. look for evidence' and then 'we satisfy that curiosity for knowledge'? (Ziman, 1978). The most powerful way of validating a scientific theory is to have its prediction confirmed: '[w]e come rapidly to a feeling of certainty that the theory on which the prediction is based must be valid' (Ziman, 1978, p.31). This predictability provides us with a feeling of having the ability to live beyond the present moment, to transcend the barriers of here and now (*ibid*). The pattern making, the linking of events and the ability to live beyond the present are also the role of narratives. Justine's approach is based on the certainty of science and expressed in such a way; science could be seen to be crucial for more than just the children.

8.3.3 Personal Style: The way to teach science

Justine, as the primary science expert on many panels, influences what is accepted by others and becomes 'good science'. For Justine effective science is not that 'wow, whizz, bang, stuff', which cannot be science as no understanding is generated. Justine dislikes the idea of science teaching as a form of entertainment. For Justine the wonder of science itself is what makes it interesting, that science makes sense:

> I hate all that wow whizz bang stuff I really can't bear it .. it seems to me to be about making a noise and making a splash and not about understanding- so I don't like the sort of school of thought within primary science - which is we have to have a wow starter .. and I just ... the wow is the .. 'wow that makes sense' or 'gosh that is interesting' or 'I really understand that' or .. 'I really want to know' not somebody blew something up and I have no idea why it happened. I get quite grumpy about all of that because it is to the detriment of science.

Such behaviour makes Justine 'quite grumpy' and does not resonate with what she thinks of as science. Solomon (2013) was not convinced that entertaining children in science was poor practice: whilst agreeing that it might not help them with the underlying science knowledge, they might enjoy science, and this was 'peripherally valuable' (2013, p.186). This incidental value exists because it puts in place a feedback mechanism between the recalling of enjoyment and the remembering the substance of the learning, something labelled as 'emotional amplification of explicit learning' (Solomon, 2013, p. 186). Instead Justine perceives learning as one thing and the 'noise and splash' as something different. LeDoux and Brown, (2017, p.2016) would challenge this view finding 'that conscious experiences, regardless of their content, arise from one system in the brain'. Gopnik (1996) suggested the very joy in science is what keeps scientists experimenting; this is the intrinsic motivation of the activity of science resulting in a feedback emotional response.

While LeDoux and Brown's (2017) study was based on the emotion of fear and not joy, they make a strong argument that the systems work similarly for all emotions and their work is a starting point to examine the emotions involved in learning. Emotional states are learnt in childhood and are developed further throughout life; they influence decision making as well as contributing to imagination, including thinking about what one's future self might feel and what the future self might decide to do. Justine remembered the science book with the activity about drinking water when standing on your head, and the feeling of confusion in secondary science when presented with the periodic table. These emotional responses are very real thoughts (LeDoux and Brown, 2017) but these emotions and memories did not stop Justine from being successful in science education, although it required personal work and the support of others. Justine's fear is still present and emerges in some situations because the paradigm is built upon knowledge.

8.3.3 Summary

Justine has explained her view of effective science and how science makes sense for the children and herself. Justine interprets science as a way of gaining understanding of the world that can be undertaken naturally by children. She understands that this joy of science can be lost because of the way it is taught apart for those who want to seem clever. Justine, like many teachers, did not identify science as different from science education. In fact, Kampourakis (2016, p.674) proposes that '[s]chool science is a distinct kind of science and neither an accurate representation, nor a vague simplification of actual science'. Justine also has a great dislike of science that does not create scientific understanding and her view of effective teaching approaches is discussed further.

8.4 Personal Style: The role of the teacher

Justine's strong view about learning being focused around children finding out for themselves, results in a specific role for the teacher: which is to prevent science teaching from becoming something she called 'frog marched discovery':

> I don't like what I would call 'frog marched discovery' where you are showing them what they are going to discover or telling them what to discover. So, I always think the skilful teacher is the one who makes or lets the children think they are discovering it for themselves but they end up in the place that the teacher wanted them to be.

This is an example of a conflicted approach to science teaching, where Justine wants the children to get to where the teacher intended but, in a way, that children think they are discovering this themselves. As shown by the earthworm example, 'Frog Marched Discovery' is not acceptable; the child needs to find out what earthworms are. The belief system in operation requires the teacher to scaffold the learning for the 'self as explainer' child (Robert, 2007). Then Justine introduces the skill of the teacher who sees the learners as a raw material in need of altering. The learning occurs when children change as the teacher intended - no longer a 'finding out together' approach, but rather one where the teacher has a clear idea of what the outcome will be, 'who makes or lets the children think they are discovering it for themselves'. This is a powerful image of a teacher, who is taking the children to 'the place they wanted them to be'. This explicit role is clearly demonstrated by an example of where science teaching did not work, in Justine's view, effectively:

> I have seen some disastrous lessons where the teachers you know talks about child directed and you think well I am afraid that is just not going to work - you know - you are going to end up **nowhere.** So, we need some sort of .. well the skill of the teacher is to direct that, to organise it.

The teacher's role is to direct and organising this learning process, something Hong and Diamond (2012) would agree with: in their American study with a reliable sample size and with the effects of pupil absence and home background taken into account, they found that 'young children learned science concepts and vocabulary better when either responsive teaching or the combination of responsive teaching and explicit instruction was used' (2012, p.295). The term responsive teaching was where the teacher knew what the children had to learn and where their role was to focus the children's attention upon it, to direct and organise learning. Responsive teaching is a type of directed teaching, informed by curricular demands, that involves choice. The Hong and Diamond (2012) study reported that responsive or directive teaching was found to be more effective than child-directed learning. There are challenges for teachers about being able to let go (Byrne, et al,. 2016) and promote a child- led response, although Justine suggests the difference between 'Frog marched' teaching and teaching that ends up nowhere is the opportunity for children to act like scientists (within the tight confines of what the teacher wants them to learn). This is difficult to manage because if children are left to their own devices, some might not build the bricks of knowledge or develop the skills required (figure 2) and 'end up nowhere', because their understanding and that of the sciences are not yet aligned. I can appreciate the dilemma, and this is an area where more work could be undertaken. Justine's view of children as scientists will be examined next with reference to parents.

8.4.1 Presupposition: the role of parents

The child as a scientist is a common theme for Justine, and she expresses concern about teachers and parents who do not enable the child to explore their world, as can be seen in the next two segments from different interviews:

> [A]nd I get really grumpy about teachers who tell me that my children are not very curious they don't have those sort of lives .. I think rubbish .. just wake them up - make the world interesting, because it is interesting - just open the door that will make it interesting to them.

Justine does not consider that science is 'unthinkable' for any child as children have a natural interest in science as it is part of their world. She also does not agree that children might not have those sorts of lives, but instead it is about opening the door. Although, Justine does acknowledge the role played by parents:

> I just think you **miss** out on this massively brilliant opportunity .. children are interested in the world (laughs) - they are interested you know .. when you are on a train and there is a child who is going 'mummy look at the drops, look at the drops on the window!' and the mother is going ' shut up, shut up!' and you just go 'oh for goodness sake' and I know as a parent - there is [everyday concerns] .. but they are interested in the world aren't they - they want to know - why this does this - and not that.

I wondered if there is a link between teachers with children who lack curiosity and children whose parents tell them to 'shut up!' Being told to 'Shut up' could influence future involvement in science, if home life influences science interest (DeWitt *et al.*, 2013a). For Justine science is interesting, important, exciting, and that it provides a degree of surprise (Ziman, 1978). The 'child who is going mummy look at the drops, look at the drops on the window' provides an example of such surprise, interest, and engagement. This perception of science as an exploratory method is used to indicate the 'supposedly unstructured and unprejudiced process of aimless investigation that the hapless pupil is encouraged to undertake' (Ziman, 1978, p.71). Justine asserts that children carry out the scientific process naturally outside school: 'they are interested in the world, aren't they?', 'they want to know - why this does this and not that', and yet 'the mother is going "shut up, shut up!"'. However, at school Justine expressed no interest in science. Now Justine sees the world from the perspective of science, but perhaps this world of investigative method is not accepted by the mother whose life may contain other challenges. Or was this mother someone who played Fatima's rules at school and was once that 'hapless pupil … before, hey presto they hit upon another great, already well-known truth!' (Ziman, 1978, p.71)? To hold Justine's view of science requires a vision from a specific place and to fail to understand why others are not standing in that place beside you.

The child watching the raindrops reinforces the notion that humans enjoy patterns, and this ability is a fundamental component in the construction of all scientific knowledge. It is this patterning that links to how humans tell stories to explain the configurations they find. Observation of natural phenomena, the accumulation of factual data, and the comparison of things in nature, are Justine's essential activities. This is her purpose for science alongside her disbelief that not all parents (or people) find this process endearing. However, this patterning occurs because 'the bodily senses are the only link between the human mind and the world he or she inhabits' (Ziman 1978, p.55). Justine expects the curious child to build scientific understanding by this 'natural process' and for teachers to direct the observations so that the learners end up in the place they need to be. However, this is a simplistic view of science and cognition and what the eye observes can just as easily provide an understanding with which science would not concur. So, children watching autumn leaves floating from deciduous trees might decide that the trees die over winter or that light things fall slower than heavier objects, yet for science these are falsehoods. For Justine, the basis of science is mainly focused upon the psychology of discovery, rather than the sociology of belief or how a scientific community copes with changes in ideas.

8.5. Conclusion

Justine is passionate about science, she is a convert to the subject, and accepts scientific realism. She articulates that all children are naturally inquisitive and that the role of science is to identify patterns and to answer the question of the type 'why this and not that'. For Justine science is for the many and not the few, even though she recognises the influence of professional bodies and their view of elite science.

In her current setting there is a strong influence of government and professional bodies – the outer circle of her SKC (figure 9). Sometimes her views and those of others on the panels do not match but she is careful not to say something crass. The influencers for Justine are the policy makers, the scientists and the influential mentor who enabled her to enter science consultancy even though she had no science background. There is an underlying fear of 'being found out' as a non-scientist. Justine's view of science impacts many teachers who work with 'little scientists' even though some of these teachers cannot see the importance of getting the children involved and interested in science. Science for Justine is all about life and it is a subject she loves and understands although she holds a somewhat naïve view (Schizas, et al., 2016).

Justine's passion for science does not include the role of science as entertainment or what she terms 'wow' science, but she acknowledges that that is increasingly a common feature in primary science. Her examples of good lessons demonstrate a link with the real world, with great science being typified by 'masses of stuff' for the children to investigate that will enrich their lives. Poor science is 'frog marched discovery', where the teacher requires the child to see through their eyes.

Justine paints a vivid picture of effective science 'as a right of all children' and believes that all children are born naturally curious. The role of teachers is to 'open the eyes' of those who are no longer curious and make them see what the world has to offer, this is Justine's world of science.

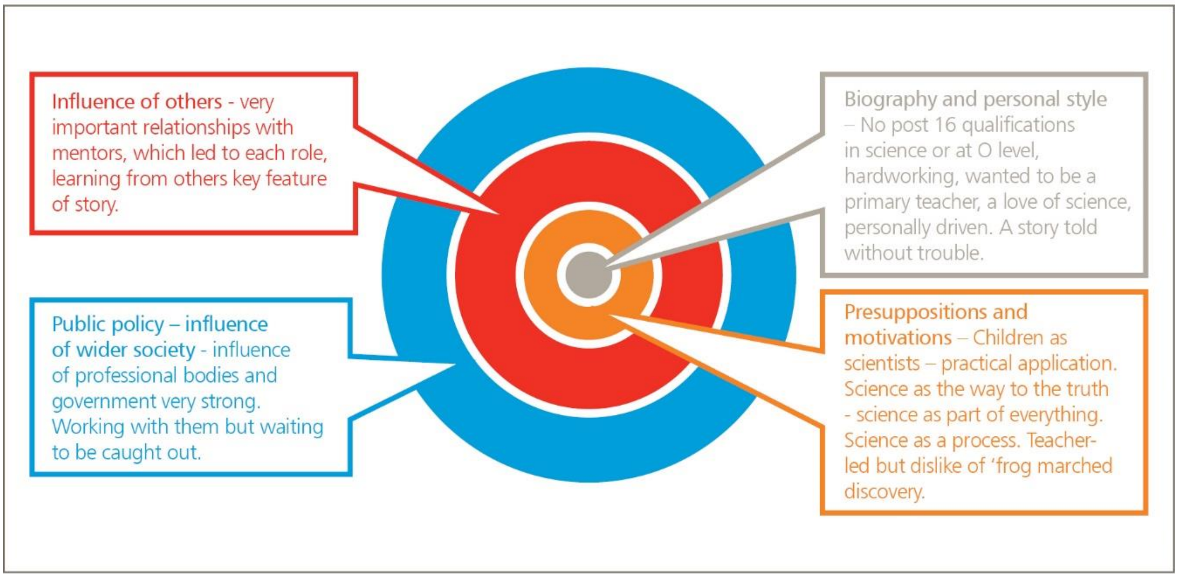

Figure 9: Justine's sphere of knowledge creation

I gained a deeper understanding of knowledge formation from working with Justine. I struggled with her contradictions between child led and 'Frog marched discovery' and the resulting unreconciled role of the teacher. Justine was brought into the world of science by her mentor, she accepted unquestioningly the scientific worldview, and how everything is explained by science; she exemplifies science gained as assimilation (Aikenhead, 2006). This demonstrated that science can be gained after school, if there is a need. This was something Solomon (2013) found in her market town research. Trying to unpick the examples Justine shared brought me back to Feldman's work on 'ontic dumping' (1987, p.137) and a realisation that this was an important aspect of science teaching and knowledge formation. It emerged here because of the examples Justine used and highlights the advantages of using multiple biographies where each person brings unique examples. I identified in section 5.4.1, 'one occurrence of the data is potentially as useful as many, in understanding the process behind a topic' (Mason, 2010, p. 1). Justine identified a specific approach to building knowledge but one which is very different from Ben's and yet they both have a major influence on the teaching of primary science. They both accept a scientific view of the world and support the building of the horizontal and vertical layers, but their gaze differs. Throughout the history of science there have been many examples where multiple ideas are found (Lakatos, 1970) and working with Justine made me look again at the need for subject knowledge to provide confidence. My learning was developed further when I tried to unpick the meaning of science teaching from the only scientist in the group.

Chapter 9: Peter – The role of the teacher crafting choices

In this Introduction I will provide a context for biographical chapter and background information about Peter and set the scene for the rest of the chapter. Peter has been involved in education and science education for more than 40 years and studied physics at university. Although Peter did not train as a primary teacher, he works with teachers and is a successful science educator. His contribution to science education is profound, as he has been involved in the National Curriculum for science since its inception (DES/WOS, 1989). The rest of the Introduction will outline the specifics of the interview process and analysis.

9.1 The interview process

I approached Peter at a conference where he was the keynote speaker. I asked if he would allow me to interview him as part of this study and followed up this verbal request with an email. He agreed, and I travelled to his place of work where I asked him to recount his science life story, and his views on primary science and teaching of this subject. I typed up the transcript and returned it but then heard nothing for more than six months. After discussing the silence with my supervisors, a follow-up email was sent, and I received not only the transcript with changes and some additions, but in addition the following information:

> I attach herewith an annotated version of the interview transcript which you sent me. I have inserted amendments or clarifications in italics, usually in brackets, and also inserted hyphens to render my comments more clear, by breaking up the flow into specific sections.
>
> As may be obvious, there are two or three strands inter-twined in my personal story, one being about developing a commitment to physics, the second being about a longer-term story of my learning about effective teaching, the third about my learning about the place of assessment in learning.

Therefore, this biographical chapter will follow Peter's own analysis of the important factors in his story set within the model of knowledge creation. Peter helpfully also provided some information on his early life within a written email. Consequently, this chapter has written biographical materials as well as materials from the edited transcript. Some of the information Peter provided would probably have made it impossible to anonymise him, so I have edited his words to ensure confidentiality. Throughout his story Peter uses Latinate words (Gee, 2011), with clarity and conviction. Peter has strong views about primary science as the chapter will illustrate but it will start with the first theme he identified, that of physics. I used the SKC (figure 4) to examine the material following Peter's instructions.

9.1.1 Biography: Developing a commitment to physics

Peter laughs a lot, is very softly spoken, and can support his views of effective teaching by using examples from projects, the history of science - including a short lecture on thermodynamics (which although very interesting is not included in this chapter) - and scientific theory. Peter never made it seem as if he had all the answers, or that science or science education were easy. Peter began his story of science by ascertaining, both in his written email and the interview, that he had no recollection of primary science within his own education.

> I can say that I have no memory of science being part of my primary education. And very little recall of science lessons having any impact in the first years of my secondary studies, but somewhere around my year 9 a new physics teacher arrived and he had a strong impact in my years 10 and 11. Then the practical work in physics began to make more sense to me than the corresponding work in the other sciences, but the main spur was in the theory, which went along with my interest in maths. I remember the physics teacher presenting the class with a question and offering six-pence to anyone who could come up with the correct answer: I achieved this, so he walked over and presented me with six-pence.

Peter did not suggest that he always knew that he would be involved in science. In fact, until he was 13-14 years old, science lessons had little impact. Peter did not mention his family or early childhood at all, and in line with my intention to do no harm, I did not pursue any line of questioning that participants did not initiate. Peter's explanation that 'practical work in physics began to make more sense' was an experience to which I can relate. The logical nature of the way physics appeared to operate (or at least the Newtonian physics taught in schools) and the puzzle-solving nature (Lakatos, 1970) of the activities was enjoyable. Peter identified that being given a prize for solving a problem contributed to him gaining a positive image of physics. This sixpence was very motivating not just in monetary terms but also that Peter was the first pupil to be able to solve the problem. These types of experiences can begin the journey into accepting the world of science (Costa, 1995). Peter went on to recount his study choices for Higher School Certificate, which demonstrates that even at this point the sciences still were not a set feature of his future:

> For making choices for Higher School Certificate study, I was not interested at all in chemistry, and for a time considered seriously the choice between one trio - Latin, Greek and Roman history, or an alternative trio of physics, maths and geography. The former depended mainly on a single teacher who had given me extra, out-of-hours, tuition in Greek (which nobody else studied) whilst the latter would involve three different teachers. I obtained distinctions in my School Certificate results in all the subjects, and only made the choice at the beginning of the autumn term. I did not regret the choice, the maths was still intriguing, the physics more so. The geography was more rewarding than I had anticipated, with a young woman teacher who gave us practical exercises with Ordnance Survey maps and took us out on field trips; I still remember in some detail one whole-day trip into

> the mountains of Snowdonia where all the stuff in the books about the effects of glaciation came alive before one's eyes.

Peter was discussing education before the introduction of A' levels in 1951, where he had to select between classics with one teacher and Physics, maths and Geography taught by three different teachers. Peter said he was not thinking long term career but about the subjects and teachers he enjoyed. Peter would have been classed as a potential scientist or a bright kid by Costa (1995): he achieved across all subjects but at this time he was beginning to identify science as personally important. Peter holds a conviction in the power of implicit learning and demonstrates, by his reaction, that such learning is linked to a holistic and emotional response - the 'effects of glaciation came alive before one's eyes'. Experiences such as exercises with Ordnance Survey maps and field trips provided greater authenticity and improved attitudes in learning (Amos and Reiss, 2012) and like my physics teacher; the power of this geography teacher was significant. In the transcript Peter explains:

> [T]he geography teacher was brilliant she … I was in school in North Wales and she took us into Snowdonia and walked around and showed us real geography pointing out to us .. that's one of the things you have been learning about and that is one of the things I write about (laughs) and that was very good.

Peter went on to study physics at university and then became involved in research projects with both undergraduates and teachers. Peter had an impact upon many different influential curriculum projects; these in turn led to an involvement in the first science National Curriculum (DES/WO, 1989). Peter has worked with teachers for many, many years and illustrates that he is very aware of the complicated nature of teaching (Loughran, 2013) alongside the need to survive in the classroom:

> I learnt that you can't get anywhere by simply telling teachers these are the research results and this is what to do: it wouldn't work because their task is complicated, it is bounded by context and it has very personal style which you don't change very easily - you have to survive in the classroom (laughs).

Peter identified early that the personal style and context of the teacher was key in teaching and he carried this understanding into all his work, identifying that teaching is a doing not a knowing environment (Beijaard, van Driel and Verloop (1999) as demonstrated later. After working for the government, leading projects and being instrumental in National Curriculum and assessment frameworks, Peter has a clear idea of what he considers to be effective science teaching. Many of his ideas have found their way into the mainstream teaching of science.

9.2 Presuppositions: Effective teaching methods

Peter identified early in the interview that school and home learning were different, something he identifies as being composed of layers. Although Peter identifies three aspects to his story - the teaching and assessment aspects are linked and the starting point for effective teaching is about knowing what learners bring to the lesson. Peter is clear about what he thinks is effective teaching, which he explained as having to start from what pupils already know:

> [Y]ou have to bring in - you have to find ways of building on what students/pupils already know and then exploring it - getting them to open it up and then working with that to change it: this is a constructivist a view of learning – you don't impose something on top, you build something from what is there already. Otherwise the person ends up with the school stuff on one layer and the everyday stuff on a different layer and they don't connect - and that is not effective - as well as not fair on the person (laughs).

Peter is a proponent of constructivist teaching as will be revealed throughout this chapter. He is also showing awareness of 'cognitive apartheid' (Cobern, 1996, p.588) where students can hold both a scientific and an everyday view of the world at the same time although Peter does not think that this is good for the learner. Peter considers that learners have their own ideas, although these are not necessarily in line with those held by scientists. There is a debate to be established about the role of the teacher and about knowledge of science *a priori* but Peter believes that teachers are influential.

Peter comprehends education as a driver for social change and during the interview he stated that learning was important for everyone. The segment below demonstrates his confidence and his breadth of knowledge, as he was discussing the changing nature of quantum theory. It also demonstrates his humanity: 'theories of fields and matter have become much more complicated, but it is such a messy field and I don't know .... I know enough to know I don't understand it but that is about all ... (laughs)'. I agree with Solomon (2013) when she said that 'each interview or snippet of one signifies to the reader something of the person' (Solomon, 2013, p.180). What this interview signified was that Peter held an opinion of the complexity of science as well as the complexity of science education. The gestalt was the complex role the teacher of science undertakes, which I will examine through a few different aspects of science teaching.

9.2.1. Presuppositions: the value of practical work

Peter considers that practical work has the potential to develop learners' understanding of the nature of science and provides them with both process skills and positive attitudes to science, a view supported by Hofstein & Lunetta, (1982). Practical work is often seen by scientists and teachers as central to science education (Abrahams and Millar, 2008) and the discussion of practical work (or lab work for undergraduates) occupied a central place in the interview. Peter stated that practical work for pupils at schools is not concerned with discovering new things but is instead about making things that are already known to others new for pupils (Millar, 2004). The aim is to make the realm of ideas link to what is observable (Abrahams and Reiss, 2010) although, as will be discussed later, not in a simplistic way. In addition, Peter understands that practical work is enjoyable but that **'pupils doing science** in school is about getting them involved and responsible rather than just recipients' [text in bold added by Peter after the interview], and that achieving change requires working with teachers and always 'thinking up investigations' - for example, 'cookie mining' where chocolate cookies are used in science lessons (See section 9.3.2). Peter supports the proposal that pupils like practical lessons (Cerini, Murray, & Reiss, 2003; Abrahams, 2007; Dewitt *et al.*, 2013; Holman, 2017) but not that being practical always equates to learning (Hodson, 1991).

Practical science provides issues and challenges, one of which is the role of the teacher. Peter states that the teacher has to make the enquiry authentic, and not merely a recipe or the delivery of canonical knowledge: 'so what you've got to do is to craft the choice of the activities to open up the enquiry's inventiveness and to see how scientific concepts meet the demands of the situation as opposed to you have to learn this because it is right'. This is the aim but not always the outcome and Peter's views are echoed by research identifying that practical science is practised 'infrequently or inefficiently' in many science classrooms (Kim & Tan, 2011, p.466). The teacher is vital; they must reveal the science that is already inherent in the practical, and to bring out more than was there in the learner at the start. This is a challenge and requires the learner to observe what science visualises, which Peter believes is only possible if the task is authentic. Peter believes that the ability to 'craft the choice of activities' requires a teacher with passion and empathy who can effect this change. There is some evidence from a small-scale study as part of the 'Getting Practical' initiative that supports Peter's need for passion and empathy: non-subject specialists who were able to empathise with their learners demonstrated better outcomes for their pupils than those teachers with higher levels of subject knowledge (Abrahams and Reiss, 2010).

Peter believes that the aim of practical activities is to enable learners to restructure their knowledge, so ideas that might have already be accepted and are current bricks in HVSK (figure 1) can be replaced by ideas that scientific accepts, as a result of working with others and the phenomena. Peter is very aware that this idea is considered somewhat naïve, since 'developing scientific ideas from practical experiences is a very complex process' (Gunstone, 1991, cited by Hofstein & Lunetta, 2004, p.32). Part of the problem is the presupposition and motivation of the pupils as well as their personality and biography (figure 4). Another issue is defining the term 'practical work', because the term can be used synonymously with the word inquiry (enquiry). However, practical work can also include any 'cookbook' experience involving activities which have more in common with following a recipe (Clackson and Wright, 1992). Cookbook science is not valid practical work in Peter's eyes, and his view of effective teaching is 'purposeful-inquiry' that is learner directed (Hofstein & Lunetta, 2004, p 31). Overall, Peter considers that practical work is a complex process and 'cannot be teacher-led or the end users will be misinformed'. Peter does identify the role of school as to generate scientists, so it is important at all stages that this work is authentic, yet Peter is unconvinced that the current system has this authenticity:

> [I]f I as a pupil think I am good at science and go on, if that is a very narrow learnt from the book exam when I go on, I am in for a rude shock (laughs). I get into a university course and find that instead of an hour or two a week doing lab work which happens in some sixth forms now, I have to spend a day and a half a week in the labs and did not realise what I had let myself in for. You are misleading that user and you may mislead the teacher of a class next year if you give a result which says these guys are good in this and this, that and the other - when it turns out they are not good at it at all.

I was struck by the dissimilarity between science education and the sciences in this section, where Peter indicates that science education is about book learning and passing exams but as a result both the teacher and user (pupil) are misled because science education is not like the sciences. The narrowness of the learning and the lack of preparedness of the user about what the sciences outside school require is a challenge. It might be that 'the rude shock' relates to their skills in lab work, where science requires a day and half instead of an hour or two. The issue of misleading is a problem in all science teaching and The House of Commons Science and Technology Committee (2002) simplified the issue by reporting that in order to improve science required just more practical work. This mismatch between the requirements of the sciences and science education is predicated on what the community at large considers as science education. Osborne supports Wolpert's (2000) stance that science is about ideas and 'experiments are handmaidens to the greater project of developing those ideas rather than the primary goal of science itself' (Osborne, 2015, p. 16). In school the development of ideas is often the regurgitation of old ideas. I am fortunate enough in my STEM work to provide Ambassadors to the Institute of Research in Schools (IRIS), where school students take part in cutting edge research. Their director provided evidence to the Select Committee on science communication (2017) indicating: 'Science education has in many cases lost its connection with what it is to do science, be a scientist.' (Parker, 2017). The IRIS students have so far taken part in science research in particle and space physics, transport, marine research, biomedical science, astronomy and materials science with one student contributing to NASA data. For many teachers, their own secondary education was a major influence on how they developed into the next generation of primary teachers (Lortie, 1975). Innovations like IRIS bring authenticity to students today and therefore the teachers of tomorrow. Peter's recent research approaches would support this promotion of authenticity and encourages a change from transmission to open ended collaborative learning. Throughout, Peter demonstrated an understanding of the complexities of education, and knew that practical work is only one aspect of the sciences. If practical is thought of as 'hands-on learning', the biggest issue for Peter is for the teacher to be able to link this 'hands-on' practical experience with the development of theory or the 'minds on' (Hofstein and Lunetta, 1982) element of science.

9.2.2. Value of 'Minds-on' activity

Practical science is a significant part of science learning (Holman, 2017). However, it is suggested that the purpose of these activities is not understood, with many teachers valuing the engagement and motivation of hands-on activities above any other outcome (*ibid*). Peter has worked in schools developing approaches to science for many years, and he recounted a project aimed at developing authentic learning through a more 'minds-on' approach, where his and the teacher's intentions differed:

> [S]o the idea was to set up small experiments, somewhere between six and 10 and the idea was that the teacher would set up these and they were all little circuit problems and they were all intriguing different types of things in these circuits and they had to discuss with one another and try and describe what was going on and that introduced a more sophisticated way of doing it and the notion was that pupils would go around in groups seeing these and then standing up and reporting to one another that was a very important part and arguing about what could happen.

These circuit (electrical) problems were part of an inquiry-based science approach which Peter, along with others, considered more powerful than direct teaching (Alake-Tuenter *et al.*, 2012). These activities contained some 'challenges and all worked slightly differently'. The intention was that groups of pupils used the equipment to think about how the experiment worked. For Peter science activities should comprise of more than just working practically, more than relating practical work to experimental evidence - there should be an element of 'discussing with each other' and 'arguing about what could happen', a view held by other researchers (Osborne and Dillion, 2002; Osborne, 2015). However, Peter's view of effective teaching and learning and the reality of practice in some classrooms did not always coincide. This is confirmed by Peter's account of observing a lesson when this circuit practical was tested in a school [bold text added by Peter]:

> [O]ne class I saw this being done and the teacher was doing these **one at a time** and for each one, teaching **the whole class** .. Which totally destroyed (laughs) the ways in which we wanted to involve the pupils in **active inquiry**. But of course, to that teacher that was his way of doing things and he had found … the sort of things we had recommended either did not grasp that it was very important but also, he found it very hard to manage.

The teacher had been told what to do and understood the practical equipment and the concepts. However, what the teacher did not understand was the general pedagogical knowledge [GPK]

(Shulman, 1986), in other words, how Peter and his colleagues had planned for the pupils to learn the intended content, with Peter saying it 'totally destroyed (laughs) the ways in which we wanted to involve the pupils in **active inquiry.'** Abrahams and Millar (2008, p.1947) produced a model for effective science work, which is useful in this debate (Figure 10).

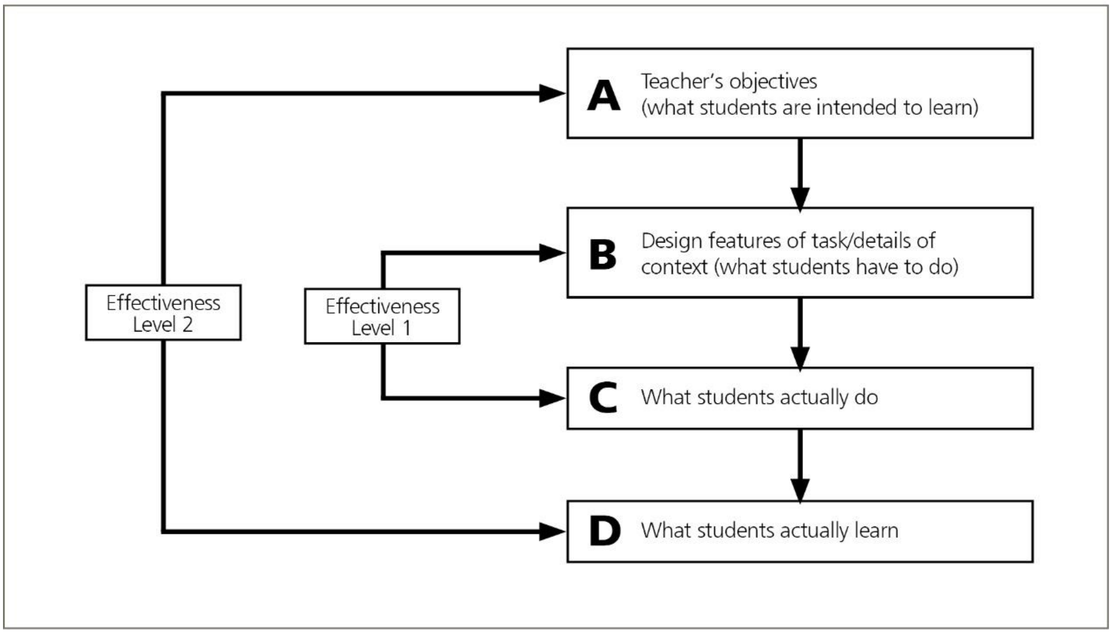

Figure 10: Effective Science work (Abrahams and Miller, 2008, p. 1947)

Peter viewed the teacher's role as one that enables discussion, promoting active learning by the pupils trying these 'intriguing different types of things in these circuits' and then encouraged them by presenting their ideas and arguing to challenge what they knew. Peter thought the lesson was unsuccessful at 'Effectiveness Level 1', the link between the plan and what happened in the classroom. Peter and the team had designed the activity to encourage interactions between the pupils' observations and their ideas - a core principle of constructivist teaching. These electrical activities were the bridge between the observable and the realm of scientific ideas. The activity was planned to enable the pupils to talk and fiddle to see what happened. Peter explains further:

> [Y]ou switched and got a current another - nothing happened - another the switch worked, and the bulb lit up and so on, then another was a one-way diode, so you switched on and nothing happened but if you turned the terminals round them something did happen.

At 'Effectiveness Level 1' there was a mismatch between what the pupils were meant to do and what they did, since the teacher's approach involved teaching the content to pupils directly. As a result, 'Effectiveness Level 2', where the pupils had the opportunity to question their knowledge and work collaboratively was never achieved. Peter thought the teacher 'either did not grasp that it was very important but also found it very hard to manage'.

There are many possible explanations: the first issue is not grasping the importance of the approach, which could be linked to how the teacher perceived science practical work, perhaps as a method to produce results consistent with canonical science (Kang and Wallace, 2005). Alternatively, the teacher may have perceived school science as a form of 'absolute truth' (Latour, 1987) and therefore considered it was important that the pupils were given this knowledge and were able to 'produce the phenomenon' (Hacking, 1983). What is known is that teachers' beliefs and actions are linked (Pajares, 1992) and it is possible that this teacher might be a subject matter expert instead of a didactical expert (Beijaard et al., 1999). The role of a teacher is complex, and this specific teacher may have wanted the pupils to learn particular things, viewing his role as 'essential and not accidental' (Westphal, 2008, cited by Biesta, 2013, p. 50). Peter and the team had taken the role of the experts, the ones who created the little challenges; the teacher was just expected to stand back and facilitate the learning.

It is impossible to know why this teacher refused this facilitator role, but this example demonstrates the complexity of classrooms, where, for example, the teachers' actions are moderated by the group of pupils they teach. So, whilst the reasons could have centred on the teacher's beliefs and values about how scientific knowledge is developed (Lederman, 1992), the reason may have been context-related - the pressure to cover content (Abd-El-Khalick *et al.*, 1998; Duschl and Wright, 1989; Hodson, 1991) or because the teacher had not planned this learning (A), so they could not visualise the learning outcomes (D) (Figure 10). Instead, this could have been the teaching method selected by the teacher on this day. What is known is that for pupils to undertake inquiry and to find out for themselves, additional curriculum time is required but that this additional time provides opportunities for metacognition (Gunstone and Champagne, 1990) which in turn provides the opportunity to link the school and home layers of science understanding. However, as Gunstone and Champagne (1990) found, students' home knowledge sometimes triumphs: Gunstone used electrical work to challenge the common view that the energy from the battery comes out at the same time from both the positive and negative terminals and '[w]hen the two meet at the light bulb there is a "clash" which we see as the lighted bulb' (Gunstone, 1990, cited by Cobern, 1996, p.583). This was one of the ideas the puzzles that Peter set were meant to challenge. Gunstone found after a series of lessons one of the pupils did not adopt the uncommon view, because his prepositions were influenced by his father, who was an electrician and who accepted the common 'clashing' view. Science is after all only one worldview and everyday applications and observations are one of the reasons why the way science views the world and common sense differs.

Peter asserts that metacognition occurs if the pupils can practice adaption, self-confidence, and collaboration, as this is what scientists do (becoming a scientist by being a scientist). In Peter's experience scientists use the primary data and transform it, but in schools the teacher and the system have some power over pupils' knowledge. Jocz et al., (2014) established that collaborative activities increased engagement with science whilst the authoritarian didactic approach adopted by the teacher reduced both science engagement and science interest. Peter believes the role of practical work is to make the link between the two domains (Tiberghien, 2000): the domains of objects and observable things, and the domain of ideas. There are links to the horizontal and vertical classifications of knowledge where the objects and observable things are in the horizontal layers and the more sophisticated ideas are found in the vertical columns (Figure 2). The fact that all observations are theory laden (Feyerabend, 1988) needs to be borne in mind although within the classroom environment this theory-laden interpretation of observations is not always considered. Peter indicated that the teacher 'found it very hard to manage' because teaching is not a simple task (Loughran, 2013), something that Peter acknowledged by saying teachers 'have to survive in the classroom'. They survive by using personal knowledge systems, beliefs, and pedagogical knowledge. Peter's belief system is bound by certainty that pupils should learn like scientists and these beliefs are influenced by his biography.

9.3. Biography: The Nature of science, the Ah-Ha effect

Peter is unusual within this study because he was a scientist and physicist first before he became an educator. His long involvement with schools started with project work and then progressed to policy making and has continued with his engagement in each of the science National Curricula, including the latest (DfE, 2013). Discussing one of the projects he was involved in, Peter reports that there was a mismatch in schools between how science education uses scientific concepts and experimental evidence, and what scientists do:

> [W]ell .. because the point of that was that the activity, often misunderstood as simply a way of relating the concepts to the experimental evidence which is certainly a good way of doing that but was far more important it was a way of identifying the sort of things that scientists do. Because if you learn science as a set of things in texts books established by great people men and women in the past, that is not bad, but you don't really understand what science is about. You only really understand it when you engage in the type of work that most scientists do most of the time. **When** I was doing research as a research student and **later** as a research fellow, I was tangling with equipment, trying to make the wretched things work - trying to wonder why that did not happen! Going off to read the theory papers certainly as well, often being forced back to read them again. Getting an experiment where you say right 'the way to do this experiment now is to scatter these gamma rays at 90 degrees to get the

> maximum effects' but the effect disappeared altogether, and we were appalled. And then realised that we had forgotten the fact – a **consequence of a general theory** – that at 90 degrees some things are polarised that way some that way (showing the effect with his hands) so then 'wow and then its brilliant it should not have happened at 90 degrees anyway' (laughs) 'Change the angle again and yes we found it again.' **That** sort of thing .. So, there is an **ah-ha** effect and you have the theory refining what you are measuring but there is also a sheer nuisance of trying to handle this stuff too and trying to make it work.

This 'ah-ha' affect was not found by researchers Tan and Kim, who examined 'pre-service' teachers' thoughts on science and found that they 'perceived that the main goal of science teaching was to teach students the correct scientific knowledge' (2011, p.275). From Peter's perspective, this is not the role of the teacher or science education. Yet the sheer nuisance of science was evident for both Peter and these pre-teachers, but there was no 'ah-ha' for the student teachers who only viewed themselves 'as a failure, and they felt embarrassed, frustrated, and worried' (*Ibid.*). It should be noted that the Tann and Kim research was carried out in Korea, where teachers teach a set of experiments or practical activities from a textbook. Teachers in the UK also follow schemes of work and published worksheets (Abraham and Millar, 2008). The Korean approach differs because Korean children often practise these activities at home yet from the experiences recounted by Peter, there is an identical aspect in both systems - the need for the teachers to 'handle this stuff and try and make it work'. Science activities do not always work that is the challenge that Peter identified and should be expected. I still smile when I remember 'the unwater [sic] plant that did not die.' Jamie (age 6 and ¾) knew it would die so he watered it. This experience taught me that set science activities fail for many reasons and that the teacher who tried to control rather than support the learning might not develop adaptive, self–reliant learners who go 'ah-ha'. Jamie did not want to be part of the world of science which would let his plant die. Peter spoke with passion and engagement as he recounted this memory particularly when he said, 'Change the angle again and yes we found it again'. This section also identified the need to check back with theory and work with the ideas of science rather than hoping the practical would reveal the 'crazy ideas of science' (Osborne, 2015, p 16) an element that might be missing in science education.

Peter's transcript, checking back with papers, could be read as the scientists finding out what they were looking for and a view of science as make-believe (Latour and Woolgar, 1979). Peter and his colleagues accepted the scientific story of the time, but on finding unexpected results, they went back to theory and then challenged their findings. They discovered that the theory was fine, but their approach was inaccurate - they were the individuals acting *in* the world (figure 4). This approach exemplifies Reed's (1992) view (see section 4.2.2) that all things are observed within the context of the current narratives because of the complexity of the whole environment. Peter was using his inner circle of style and biography, working with the ideas of Gamma rays current at the time but bound within the social setting, so having to check back when the results were unexpected. Many years later he uses this biographical knowledge to discuss this reality of life in science beyond the classroom, where 'problems don't come out in parcels.' Peter's remembered frustration was very clear as he recounted the problems with 'tangling with equipment, trying to make the wretched things work'. Peter went on to reveal other ways in which science and science education differ:

> [S]uddenly we are dealing with some radioactive sources ever so carefully, so we thought and then someone put their hand under a Geiger counter and found their skin was radioactive and rushed off to scrub their hands to remove the tiny traces of radioactive material and learn to be much more careful – that is the reality of life beyond the school classroom- any scientist is dealing with real problems with the world outside: the problems don't come out in parcels – you have to be adaptive, you have to be self-confident. Also, to a certain extent you have to be collaborative – ask any industrial body what they really want in people and they want people to work collaboratively in groups.

Peter discussed the importance of real problems, the need for scientists to be adaptive and self-confident and he alluded to the mismatch between the world of work and the requirements of the education system. Peter is also showing how his current world of science education was created by his biography when he worked as scientist. These experiences form part of his SKC and because Peter as a scientist worked on problems together with others, he values collaboration. Yet in the classroom the teacher is often alone, they do not have a group to work with and societal pressure often focuses learning of small parcels of isolated, testable knowledge. The sciences with the big teams (Elgin, 2011) require adaption, self-confidence, and collaboration so the effective teacher would therefore need to promote these competencies with their pupils if they were to provide scientists of the future. The teacher has many roles as will be demonstrated next.

9.3.1. Biography: you are not a teacher.

In some of the other biographical chapters I have discussed some of the different roles for a teacher, for example the all-knowledgeable sage, the facilitator, and the enabler (McWilliam, 2009). The feeling that the teacher must be the all-knowing sage – the one in charge - is demonstrated in this quotation from student teachers:

> '[y]ou are the teacher. You don't want to say I don't know why this happened or why that did not turn out as supposed to be. I would feel a bit embarrassed or panicking'
> (HJ. Tan and Kim, 2011, p.276).

Being a teacher is not a simple role, as demonstrated by the range of reasons that I provided for the teacher who did not carry out the electrical activity as requested. One of the influential memories for Peter occurred more than 30 years ago, and he still carries strong feelings about this event. For anonymity I have replaced the name of the project and funding group with 'X':

> The other effect on my ideas about teaching came about when I was asked to be the joint-leader of the initiative for X. I was quite surprised to be invited to be the joint leader of a team - of six altogether: the other five, unlike myself, were excellent and experienced school teachers, my task being to ensure that for any topics which we wanted to introduce for the first time at school level, that these were presented in ways which, whilst simplified for that level, were nevertheless authentic. I recall one meeting when I presented a conceptual map of the issues concerned, and one of the teachers thanked me for this as a very helpful guide, but said that I should now shut up as they discussed how to teach it, because I knew nothing about teaching: that hurt, particularly because I had by then come to learn, from him and the others, that it was true.

Peter had a clear idea of what effective knowledge of science was needed in this new area, but he was also aware that teaching require authentic activities. His role was to translate the science into science education which was the 'know what' rather than the 'know how' and once he had done this he was told to shut up. Peter obviously reflected upon this episode and added in his email something he did not include in the interview but nevertheless felt was important. The material he added concerned effective teaching style from his own education, (Lortie, 1975). The context is about physics, but the substance is about teaching and learning:

> [T]he physics study remained my first love. This was enhanced in my physics undergraduate course: here the quite famous head of department surprised us all by giving one of the main first-term lecture courses to us - he then the spent the lecture time developing a few topics in detail, some related to his own current research some exploring one or two topics in the philosophy of science. I have only encountered one other university lecturer since that time who made one look forward to the next lecture. I was only courageous enough, after working for several years as a physics lecturer, to copy his approach so that I did not have to spend lecture-time talking through them but would open up a more relaxed discussion on a few selected topics.

Peter is again using his own experiences of knowledge acquisition to model future action, how to make the learning interesting and motivational. The lecturer was able to bring Peter alongside by using the real-life examples of current work, so that Peter looked forward to the next lecture. This is very different from an approach to science which results in a loss of intellectual autonomy because people (pupils) are being persuaded to accept only scientific answers, which leads to a blindness to other approaches (Feyerabend, 2011). This is learning as a lively process and not accepting 'finished science' (Bruner, 1996, p 127). This section of Peter's responses also demonstrates how teachers play an important role in developing learning but also influence the learners' future approaches to education. Peter has a view of science informed by his time as scientist; he has a science but not a science education worldview. Over his extended time working with teachers Peter is aware of the challenges of science in a classroom and acknowledges that trying something new requires courage. Peter's account included two emotional responses one positive- looking forward to the next lecture, and the other problematic - the need to have courage as a teacher. Courage is the ability to do something that frightens you, whilst confidence is about personal abilities. I welcomed the idea of bravery which makes science teaching open to all learners. Throughout the interview Peter demonstrated clearly the deep involvement he felt for science and science education, but he identifies them currently as being two different things. Peter also identified other qualities and characteristics he felt were desirable for an effective primary science teacher:

> [S]omeone who found the subject fascinating because if they didn't it is much more difficult. Secondly one who wants to shine, set a light in the eyes of the pupils when they try something and build on that so that it leads them to have a more developed understanding through getting them involved in arguing about what they have observed or made to happen, it is that fermenting of imagination and of argument which matters.

The successful teacher is fascinated by science, suggesting the emotional affective domain is an important aspect of teaching. The effective teacher will get the pupils engaged, 'set a light'; another example of the implicit learning outcomes which Peter reasons will lead pupils to want to become enquiring adults. The effective teacher will develop understanding by the process of argumentation as '[c]onnecting the "hands-on" work of scientific inquiry with the "minds-on" work of developing scientific ideas and theories' (Osborne *et al*., 2016, pp.821-2).

Peter wants learners to develop both construction and critique. Construction uses the current ideas of science (the knowledge and imagination) but critique is needed then to question whether these ideas still work. Critique and construction together are the method of science (Osborne *et al.*, 2016). For Peter, the good primary teacher uses the skills of construction and critique alongside something that Peter calls 'fermenting of imagination', it is the fermenting the imagination and being able to argue about what you see, not an accepting of science, because it is right.

9.3.2. 'Fermenting of Imagination'

In order to gain access to authentic activities, pupils must be given opportunities to carry out inquiry rather than recipe science. Peter explains the importance of

> trying to open up the spirit of inquiry and investigation which is essential for the future of education generally and that connects with what I was saying about pupils doing science in school getting them involved and responsible rather than just recipients .. ur (cough) so we

> are thinking up with colleagues here and two or three splendid teachers thinking up investigations to give pupils initiative to try things out … and also some things are quite weird .. cookie mining... what is enormously fun. This is the way when you release children's imagination and inventiveness you get all sorts of things happening. So, I think the future is to channel that into areas where they will .. first of all, they will learn that science is like this and will be involved in it.

Cookie mining involves using different types of chocolate chip biscuits, squared paper, cocktail sticks, and paperclips. The chocolate chips represent the mineral content that needs to be released with as little damage to the biscuit as is possible: to 'mine' the cookies without damaging the land. There is no set way to complete this activity and learners need to use imagination, teamwork, and a trial-and-error approach. The aim is for learners to give reasons for their actions and support their ideas (construction) as to why what they did would be beneficial (critique). Peter suggests that cookie mining represents 'real science' and makes this an authentic science learning experience. The activity does not include 'explosions', but learners with whom I have undertaken this activity have reported it as enjoyable and have been fully engaged in communicating and arguing about their approaches.

Peter identified the practice of science as about developing implicit understanding and intuitive procedural skills so that future exploration and experimentation is possible (Sahdra & Thagard, 2003). Ben would not approve of this activity because there is no explicit Vision I outcome only an opportunity '[t]o develop higher level skills and attributes' and '[t]o motivate and engage students' (Holman, 2017, p. 18). Yet it exemplifies Peter's core belief of a feedback mechanism between enjoyment and learning that will permit children to access the world of real science when authentic activities are undertaken.

9.3.4 Summary

Peter's story is about effective learning which requires practical work that is authentic, not a recipe. Peter has a clear view of how hands-on learning in science and science education should enable an 'ah-ha' moment and that learning involves the affective domain. Teaching is complex and involves many decisions and requires courage and Peter does not think everyone can be a teacher. Peter does not exert power over teachers, nor does he tell teachers what to do. He thinks effective science teachers can 'shine the light' and release pupils' imagination using authentic activities which reflect what science outside school is like. Next, the last of Peter's themes will be discussed - that of the place of assessment in learning.

9.4. Peter's learning about learning.

Assessment for Peter is not only about testing: it is about teachers finding out pupils' ideas and thus assessment becomes authentic. In the examples provided it is also clear that for Peter, assessment is an integral part of teaching and as a result, his belief about the nature of science is also uncovered. Peter described an activity that helped teachers understand what pupils thought, and thus informed them of their science ideas. This activity also provided practical opportunities for the learners to discover their ideas and to invent their own understanding of science:

> [S]tudents are in pairs and then one sits in a chair and one stands behind and the one in the chair has a mirror or just a piece of shiny aluminium foil or something and the one behind has a torch and the guy with the torch has to switch it on and off at random as it were and the one in front has to be able to tell on-off-on-off as it happens **from watching the reflection**: that is simple then draw a diagram of what happens .. and then pupils have to find out how to represent light. **It's** best to provide them, we found out, with an outline of someone sat on a chair with somebody standing behind them and so on and **holding the** torch and the person on the chair holding something so **pupils have to focus on how do you draw the light**: some drew dotted lines some drew straight lines some drew clouds of stuff some drew dots going all over the place some people with lines had arrows on them sometimes the lines went from the torch to the mirror sometimes they went from the eye to the mirror (a very old Greek belief about sight that you actually did something to look at it rather than something coming into you) but you started a discussion about that **'why did you draw it like that?' 'how can we draw light?'** but it was an opener up … because it put it to them to invent something first.

Peter here identified that the pupils had to think about how light travelled and how the pupils understand light and represent it as: 'straight lines', 'dotty lines', 'clouds of stuff', or even 'dots all over the place'. Within the children's ideas are all the ways that scientists over time have understood light, what it is, and how it travels. Peter identifies the 'active eye' model of the ancient Greeks and, therefore, how specialist knowledge has changed. The activity also allowed the pupils to invent their own ways of showing how light travelled and this was what Peter called an 'opener up'.

This is a very simple practical task that provides an opportunity to find out what pupils know. Although Peter did not give the history of the science of light, the history of science does inform his views as will become apparent. This section of the interview made me consider what is known about light, and whether light is particles, clouds, dots, or lines, is still the subject of debate by scientists today. The primary science curriculum (DfE, 2013) uses the ideas of Newtonian physics invented by Isaac Newton himself i.e. that light travels in straight lines. I use the term 'invented' by choice as 'discovered', the term used in school science, suggests this was discovered as one of the laws of nature. Whilst assessment helps teachers find out what children know, it is predicated on a model of science which stresses that '[i]f students are given an opportunity to construct scientifically orthodox conceptions, if they then come to see that these conceptions are more intelligible, plausible, and fruitful than other conceptions, the students will change their conceptions for scientific ones' (Cobern, 1996, p.579). Yet this is problematic for many students (of all ages) because 'Scientific knowledge is not 'organized, common sense'; it is a world which begins to exist only when common sense and all of its postulates have been forgotten or rejected' Oakeshott (1933, p. 171). I remembered my own enjoyment when finding out pupils' ideas but then having no practical way of bringing these ideas to the scientific view (see section 1.2.4).

Peter is well versed in the history of science and one of the advantages of interviewing him at his place of work was that he was surrounded by his publications:

> *This* thing on Earth in space (Peter points to a book on the table) I was struck looking at that again .. ur .. people's view about the sun and how the sun worked and how that changed all the time – how they had pictures of the Earth as *the flat base of a hemispherical* bowl and the sun moving around and so on. *The* interesting thing about that is you find that one of those versions is actually in the Old Testament. If you look at the story of creation in the book of Genesis, or in the Psalms related to that, they are built on a model of a flat Earth: the firmament comes up in the Psalms as a hemisphere and the sun goes around the hemisphere and the Earth is there having been drawn by the creator out of the waters and the whole of it is there and these children are reproducing it.

Peter explains the seductive nature of children constructing ideas, particularly if their ideas mirror what is in the bible. Accepted scientific knowledge can become part of the common knowledge (as discussed with the example of a thermometer (*see section 4.3.1)* or accepted knowledge can change (section 2.1 and 3.2.2) both are an important component of the sciences. This knowledge can be constructed by people with a science view without requiring a debate about reality. Peter suggests that it is only by using ideas from the past that science education can 'explain how one view replaced the other', sometimes because the change of ideas is conceptually challenging, and, in the example of the Earth in Space, these many changes happened in the 'thousands of years between the Old Testament and the modern version'. Peter accepts that the knowledge created over the millennia needs to be taught so that new knowledge can be built upon it.

I enjoyed listening to Peter discuss Ptolemy's patterns of the solar system and that 'once you allowed the Earth to move from the centre all these patterns became much simpler'. I believed that Copernicus was too godly to promote his theory, so my story was influenced by the Church and society's view of knowledge. Peter narrated instead a disbelief account as Copernicus reasoned that if the Earth was at the centre it would move at a few thousand miles an hour and, 'people would laugh in his face and say why are we not blown off, it was obviously nonsense'. Peter's version demonstrates how the stories of science have different versions: my version was influenced by ‘science as saviour’ narrative and his by informed reading. Peter suggests however that some of these ideas, even told from a historical point of view, are too complex for primary children. Peter did not think that in primary school topics such as colour, floating, and sinking, nor the Earth in space, should be taught because it was impossible to explain the history of the ideas simply enough. These ideas were removed from Key Stage 1 in the latest National Curriculum document (DfE, 2013). There are also some aspects of forces that he would want not to be covered, as he explains:

> [T]rying to relate those motions to physics … so how do things that we push around move and then you get into a hell of a trouble because if you push things this way (signals in the horizontal direction) the bigger and heavier they are the harder you have to work to make them move but they fall naturally that way (signalling the vertical direction) .... so, on and so you have a long story and to try and do that at primary level there are so many other things you can do, why bother with that?

‘Why bother?’ was a comment that surprised me, but Peter makes a valid point. If these facts are to be taught and assessed, trying to get children to accept very abstract ideas that contradict their everyday observations is a challenge. Evidence from research into constructivist teaching demonstrates the difficulty in trying to change children’s ideas and so teachers have to impose a science view leading to cognitive partied (Cobern, 1996) and with the children maintaining their everyday view. In addition, if the role of primary science is to fascinate and encourage imagination in younger pupils then long stories of science are not necessary at this phase. Indeed, using them might result in Stephanie’s worry of teachers losing children.

9.4.2. Conclusion

Peter wants primary children to undertake science, but he thinks they should not have to struggle with things that are too complex and where everyday observations conflict with science knowledge. Teaching science should consider how ideas have changed over time, rather than promote the cumulative view of scientific progress. Peter works in a logical way and understands assessing learning as fundamental to teaching, and that assessment starts from the children’s ideas. Peter’s biography before he found physics fascinating was not important to him, supporting Polkinghorne’s stance that the significance of events was based on ‘the outcomes that followed’ (1988, p. 21). Peter’s geography teacher was instrumental in developing his presupposition that practically seeing things helped make learning meaningful and brings learning to life. His own time as a scientist informed his view of what science should contain and that authenticity and collaboration are vital. Peter was hurt by being told to ‘shut up’ when he was leading a project, and this has informed his future approaches with teachers. His attachment to constructivist approaches is associated with his research background and a great number of his presuppositions about teaching have been informed by working collegiately. In his story he mentioned an instrumental person who was skilled in primary science; I have removed this section because anonymity would have been impossible. (Figure 11):

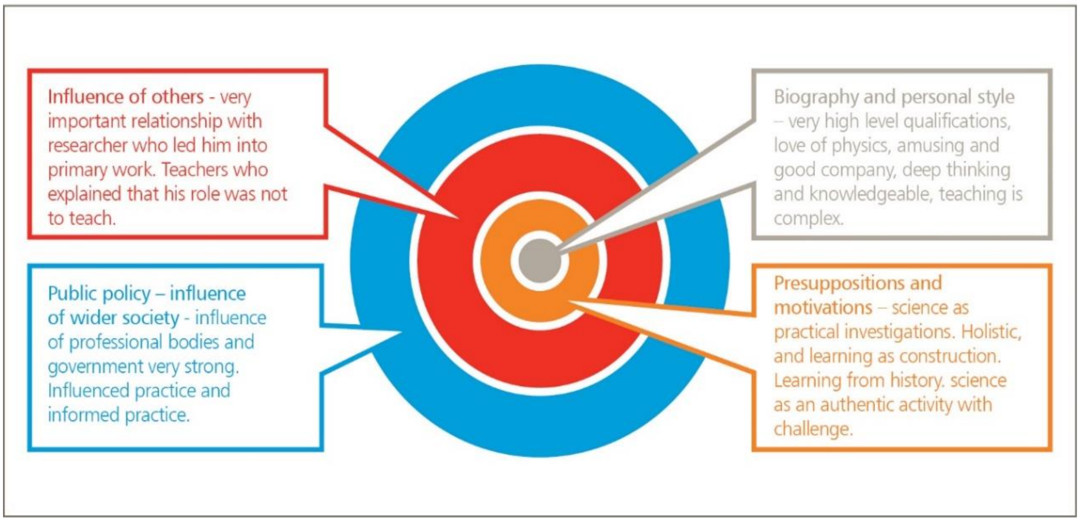

Figure 11: Peter's sphere of knowledge creation

This chapter will end using Peter's own words about what he saw as the current issues in primary science:

> [W]ell …. I think we made it too formal and not exciting enough and perhaps … in some ways too ambitious and in some ways too misleading about it. We need to involve the pupils in inquiries where they had to make the decisions on what to measure, how to measure it, how to set it up, that sort of thing. That part of science education has got lost and because of that people are turned off.

These are some of the themes that will be gathered together in the next Chapter.

From listening to, and discussions with, Peter I learned his views about the role of the teacher and that how teachers behave is very diverse. He believes that a teacher's decision making might relate to their pedagogical content knowledge (Shulman, 1987) and that people outside of the classroom and school context might not understand this. I was reminded of Jonas Salk's view that Latour and Woolgar (1979) had identified the things that were easy to understand but were not events that scientists working at the Salk institute identified with (section 3.2.). Discussing science with Peter was like talking about science with STEM Ambassadors who I work with but this very different to the science told by science education. Peter played a major role in his chapter, identifying what was selected and how it should be shared; it was a genuine pleasure to listen to his views and in the final chapter I will attempt to bring some of my overall learning together.

Chapter 10: Revisiting ‘My Story’

I started this work to examine three questions and here I explore the outcomes of this endeavour, alongside the changes that have happened to my understanding of science. The questions were:

- To what extent is the following paradigm for primary science accurate, namely: poor teacher subject knowledge and confidence leads to poor pupil perceptions of science. Moreover, how is primary science understood in literature and reports?
- What contribution can an auto/biographical narrative enquiry make to illuminating problems, and or possibilities, for primary science by engaging with the lived experiences of a sample of primary science educators and by referring to their own learning lives?
- What might be the implications of the above for teacher education and primary science, including the initial training but also the CPD of science teachers?

10.1 Introduction

The participants’ case studies were interpreted in the light of current events rather than events of the time in which they occurred; this is also true of my own narrative. The events in my life are now events of a different kind when examined with the new knowledge I hold and this is a kind of world-making (Goodman, 1978). I accept that any worldview is not a necessary view, and that other views are possible. Each viewpoint is a yardstick by which ideas are exchanged and sometimes old, or even erroneous, views, are useful. For example, when sending a rocket to the moon a heliocentric worldview is not as helpful as a pragmatic geocentric position (Siemsen, 2014) because the journey is from the Earth and requires an Earth-centred perspective. In discussing primary science education through the lens of these life stories, it appears that many worldviews can operate at the same time: in the same way that there are many different currencies across the world (ibid), and this is only noticeable when an exchange is needed. This exchange was only obvious when I began to listen to the life stories of successful science educators, moving from the familiar to the unfamiliar, as I also learnt more about my own views. The challenges in this work have been about looking at a subject I thought I knew well but I now realise that erroneous scientific thinking has dominated every part of my life. This chapter will begin with the changes to my sphere of knowledge creation that are a direct result of undertaking this study.

My views of science and the sciences have altered and my frames of referenced changed. Chapter 1 reflected upon my personal science life story and the structures and approaches I have used. My sphere of knowledge creation (SKC) at the start of this study is presented in the diagram below (figure 12) The events, such as collecting shells, were part of a process that changed my naive views and can be examined against my current SKC (figure 13). The greatest change is in my presupposition and motivations, as outlined in Chapter 1, from a naïve positivist approach of science to a critical realist position.

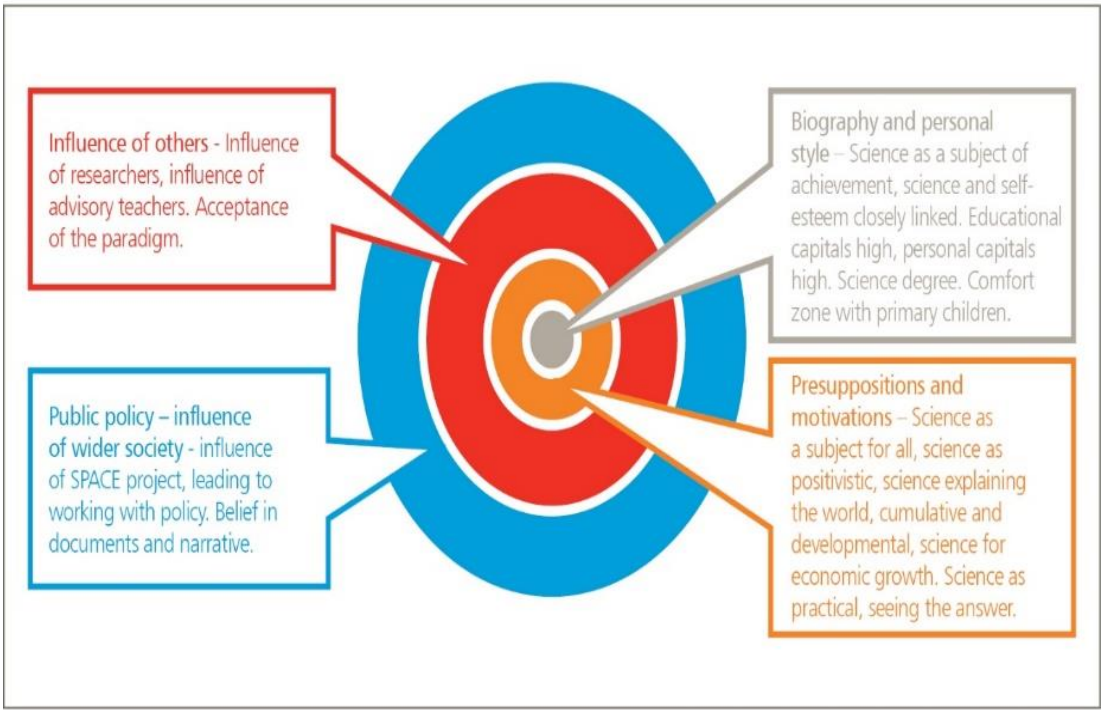

Figure 12: My Initial sphere of knowledge creation

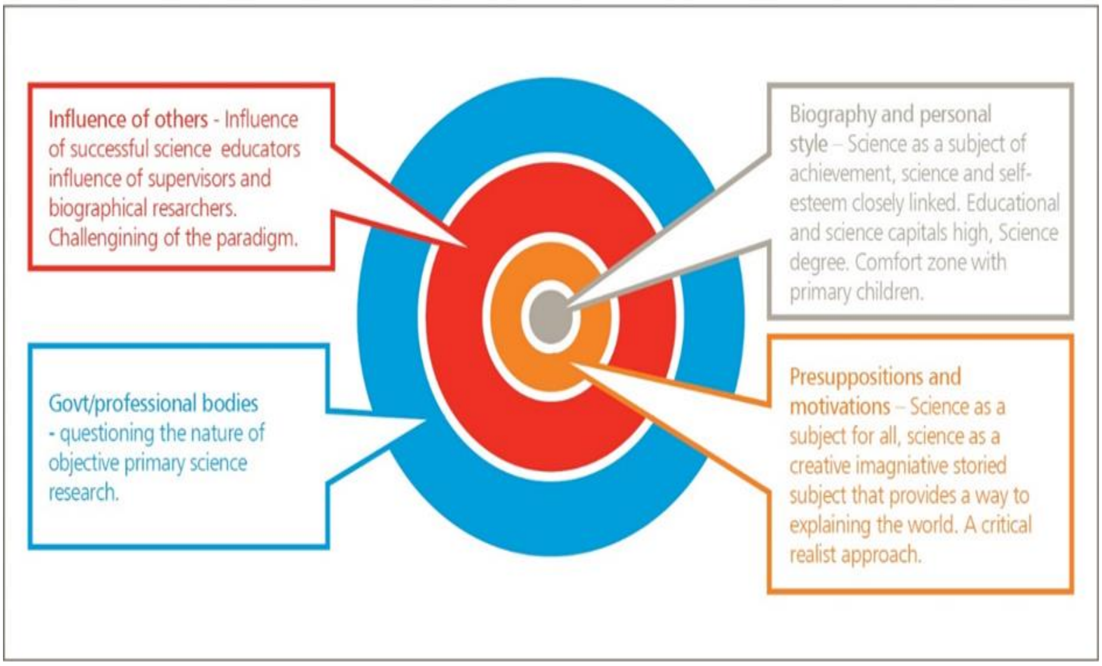

Figure 13: My sphere of knowledge creation now

In this chapter I will examine my learning in more depth, starting with some answers to the first research question, and accepting that this is a writing convention as all three questions have been linked throughout this work.

10.2 The paradigm revisited

Whilst quarks, water, and the colour red are classifications each in a natural group or kind, indifferent to their classification (Hacking, 1999), human beings are not unresponsive to the way in which they are classified. People who are classified in a certain way begin to behave according to that classification. Traditional primary science research (Osborne and Simon, 1996; Harlen and Holroyd, 1997; Beggs and Murphy, 2005; The Royal Society, 2010; The Royal Society of Chemistry, 2014; CBI, 2015) has treated primary science teachers as an indifferent kind. This has resulted in a narrative where it has become acceptable to state that a lack of confidence is the reason for not teaching the subject, even though viewing the complex beliefs and behaviour of teachers on single dimensional lines is inadequate (Apostolou and Koulaidis, 2010).

The current student teachers entering the profession are very different from the teachers discussed by the HMI (1978), when I was still at school. The dominant narrative of primary science was first identified in this HMI report which recognised the lack of science subject knowledge and confidence of teachers involved in primary science. This resulted in the consideration of behaviours and feelings. For example, over many decades, primary science has not only been impacted by the construct of confidence and effectively turned it into a condition, but it has also labelled primary science teachers into a 'type of person' (Hacking, 1999). The agents within this story (Bruner, 2004) are participating in primary science within a powerful narrative of public science created by Whewell and associates (see section 3.2). The power of science emerged in different ways and was discussed by Justine (Section 8.2.2) who identified the professional body who were caught in a conundrum: they wish to 'keep the cachet of [the subject]' but discuss elitism as an issue. Ben's biography demonstrated the power that consultants have over teachers (section 6.4.1). Elitism, tradition and passion all define Ben. His outrage at the example of the 'sweating plate' (Section 6.2.1) shows both his commitment to a traditional science education and his passion. There is also power of a specific science stance inherent assertion that there is only one way to attain knowledge. Stephanie was scathing when discussing the teachers who had to attend a knowledge course, but who could not see how it was of any use. Her view that the 'get them to GCSE by lunch-time' approach (section 7.4.2) where the 'teachers were still not getting it' was ineffective and supported by research data (Kudenko, 2015). I wondered if those commissioning these courses have a view of science which they wish the teachers to adopt. Their approach contrasts starkly with Stephanie's approach to science which enabled her to let a child**,** observe snails for a day.

This dominant narrative of primary science has been retold to the next generation of student teachers through the literature that exists (Harlen and Holroyd, 1997; The Royal Society, 2010; RSC, 2014; CBI, 2015) and as such reinforces the dominant narrative of limited knowledge and confidence which in turn is said to influence pupils' interest in science. However, there is little evidence that pupils have poor interest in the sciences (see section 2.5.2). It is perhaps necessary to separate the people (teachers, educators, and researchers) from the behaviours of science teaching in the classroom. It is possible that limited research evidence has been used accidentally to create a myth that primary science teachers typically lack knowledge and confidence (Osborn and Simon, 1996; Harlen and Holroyd, 1997; Beggs and Murphy, 2005; The Royal Society, 2010; Royal Society of Chemistry, 2014). Whitehead and McNiff (2006) would suggest that these are an example of normative assumptions. Until I began this research, I would have accepted the dominant narrative, and indeed, I would not have been employed as an AT if government had not been aware of this problem. Twenty years on, teachers now all have more science knowledge and it is not possible to train as a primary teacher without a GCSE qualification in science. I have come to acknowledge that while there are individual teachers who lack knowledge, it is not true of the whole group. In addition, effective teaching approaches might not revolve around the teacher as the sage (McWilliams, 2009). I have examined this dominant narrative and Table 2 collates some of the evidence for and against the narrative.

Table 2. Evidence for and opposing the dominant narrative.

Supports the dominant narrative	**Questions the dominant narrative**
HMI (1979) report identifying the lack of knowledge and confidence of teachers**.**	More than 1,350 science coordinators attended a 35-day course, paid for centrally (HMSO, 1989). Continuing professional development does not guarantee improved levels of confidence (Lloyd *et al.* 2000)**.**
HMI (1989) 'the ability of teachers to select and utilise subject material matched to the interest and abilities of the pupils they teach' (HMI 1989, p.6)**.**	Research disregarding data that did not fit: for example, the teachers who expressed a confidence in science (Beggs and Murphy, 2005). Minimising the 44% of teachers who did not have a science background but whose science was sound (Harlen and Holroyd, 1997)**.**
Primary teachers who had limited knowledge and lacked confidence to teach this subject (Wragg, Bennett, and Carre, 1989; Bennett et al., 1992; Sharp et al., 2009).	Could it be that teachers lack ideas that work; Appleton (2003) defined these as science activities that are successful in the classroom and provide a starting point for future work.

Coping strategies such as didactic 'chalk and talk' and rote learning methods (Harlen and Holroyd 1997; Appleton and Kindt, 1999).	That there are unprepared teachers and poor teaching in primary science is far from clear (Lunn, 2002; Ofsted, 2011).
Royal Society, 2012 – need for specialist teachers. RSC (2014) – specialist teachers result in greater learning – quoted Poland who have specialist teachers.	The share of top performance in at least 1 subject was 16.9% for UK compared to only 15.8% for Poland, (OECD, 2016, p.12).
Royal Society of Chemistry, 2014 – poor teacher knowledge results in risks to economic development. The answer is to 'provide more CPD' (RSC, 2014).	More students transferred into STEM based courses than transferred out, and as a result the STEM shortage is a misnomer (Salzman, Kuehn and Lindsay, 2013). ARM reported that 'the skill shortage is created by the employers being too inward focused' (2016, p.8) rather than there being a shortage of graduates. Research not clear (Xie, and Killewald, 2012).
'The oft-reported under-confidence among teachers in teaching science is undoubtedly related to lack of science knowledge' (Beggs and Murphy, 2005 cited by The Royal Society, 2010, p.83).	Researchers are not in a position to know, and may base their ideas on limited evidence, and not 'what actually happens in classrooms' (Beggs and Murphy, 2005, p.121).
The National Audit Office (NAO) confirms that teaching is of better quality where secondary chemistry and **primary science** teachers hold qualifications in the subjects they teach. (RSC, 2014, p.4).	The NAO document cited by the RSC using the term '**primary science'** produced no matches.
Limited teacher knowledge (Abell and Roth, 1992; Alexander *et al.*, 1992; Harlen *et al.*, 1995) influences teaching quality.	Generalist teachers displayed greater positive attitudes, balancing out the inferior preparation and less satisfactory styles of science teaching (Zuzovsky, Tamir and Chen, 1989). Non-subject specialists empathised with their learners resulted in better outcomes than those teachers with higher levels of subject knowledge (Abrahams and Reiss, 2010).
'Many primary teachers not only lacked confidence and competence to teach science, but they also possessed an incomplete understanding of science concepts' (Smith, 2014, p.467 citing Jarvis and Pell, 2004).	Jarvis and Pell study collected results in outcomes that were not statistically meaningful, due to a loss of detail and correlation issues (Reid, 2006).

This dominant narrative could be said to have become ingrained, and thus current research continues to ask questions about confidence, demonstrating that society still considers this belief to be relevant (Wellcome, 2017). Responses from primary teachers, have established now that few teachers lack confidence (Wellcome, 2017, p. 5) (Section 2.6) [see Table 1.]. Confidence can be thought of in different ways, and like the subject 'Science' it exists (Heidegger, 1927) both in time and in the logical, mathematical objective world. Confidence defined in different ways (see section 2.4.2) is discussed in daily life but this does not make the construct of confidence valid. I began this work within the mathematical, scientific, logical world but now accept that there are other worlds and that ‘according to our temperaments, we prefer the contemplations of one or the other’ (Russell, 2001, p.19).

The issues I grappled with were not new: long ago Berkeley’s strong form of instrumentalism identified science as a convenient fiction that organised experience, saving science from scepticism (Rosenberg, 2005). I naively identified the idea of a successful science educator, who would have national standing, and even wondered whether there was a ‘*unitas multiplex*’ (Feldman, 2005, p. 29) to explain the ‘group think’ that was related to their success. Group think exists in the Vertical Knowledge structures in my model of knowledge (see section 4.3) and there is a gaze (see section 4.3.2) that promotes Whewell’s concept of science and includes hands on experiences and science as the way to interpret everyday life. It has become apparent that these successful science educators were unique and although there were similarities, there were also differences in their views of primary science. These differences emerged to tell of ‘overexcited children who love science’; ‘the less able children for whom the role of science was uncertain’; and ‘the variety of teachers, undertaking the action of primary science teaching in complex situations’.

Primary science, as told through the stories of these successful science educators, is, like living a life, not a symmetrical experience (Safstrom, 2012). These educators demonstrated knowledge of the setting (Bruner, 2004), with an awareness of the dominant narrative that teachers lacked knowledge and therefore confidence, which contributed to their classifications as successful science educators working with others who might be perceived as less successful. They told stories full of characters, for example: Stephanie’s P.E. teacher who is reported as saying ‘I am not going back to P.E., science is wonderful’ (section 7.4.1); Justine’s ‘parachute’ narrative led by a well-meaning teacher ‘that was just a bit pointless really’ (section 8.3.1); Ben’s later acceptance that he identified people doing things wrong a lot of the time (section 6.4.2); and Peter whose teacher did not want to facilitate learning (section 9.2.2). These personal narratives illustrate that these successful science educators understood, and were aware of, the dominant narrative of primary science teaching but, in addition, their stories had existences of their own.

Initially, working alongside the participants contributed to my acceptance of behaviours and feelings that are part of primary science teaching, but I began to question if the influence of particular research (Osborne and Simon, 1996; Harlen and Holroyd, 1997; Murphy and Beggs, 2002; Beggs and Murphy 2005; The Royal Society, 2010; The Royal Society, 2014; The Royal Society of Chemistry, 2014) on the educators resulted in them identifying and valuing particular narratives of primary science education. Moreover, it occurred to me that these narratives might have then changed the science educators’ understanding of themselves (Hacking, 1999). Except for Peter, I think this is a correct assertion. Peter is different as he does not try to tell teachers what they should do. He does not hold a simplistic view of teaching and therefore does not take the role of the 'powerful other' in the same way as the other successful science educators.

Reviewing the research on the dominant narrative, it is apparent that some of the research focused on emotion rather than evidence, for example: It is widely agreed, including by the Department for Education, the National Audit Office, and the Wellcome Trust, that subject-specialist teaching greatly enhances science education (RSC, 2014, p.1).

The supposition that secure personal subject knowledge automatically results in more effective practice is challenged by Cochran-Smith and Lytle (1990). I have indicated previously that subject knowledge and classroom performance might be unrelated (section 9.2.1). Coe et al (2014) also consider that this traditional view is flawed by imprecision and faulty assumptions. Guerriero also questions such positions and suggests:

> There is a long history of discussion and debate around the connection between teacher knowledge and quality instruction, there is a lack of empirical research testing of this hypothesis or even connecting knowledge to student learning (Guerriero, 2017, p. 109).

Guerriero does go on to state that general pedagogic knowledge is relevant to quality teaching and suggests that there is a competency involved which increases as teachers become more experienced and that this influences pupils' learning. In some of the research there was a preoccupation with negative findings which I found to be a concern, especially when used alongside the use of emotive and common-sense statements such as: 'If we want to send our children into the world equipped to meet those challenges then we should not send our teachers unprepared into the classroom' (RSC, 2014, p.1). The evidence supporting the belief that there are unprepared teachers and poor teaching in primary science is far from clear (Lunn, 2002; Ofsted, 2011) and nor is there consistent evidence that continuing professional development guarantees improved levels of confidence (Lloyd et al. 2000), yet I suggest that the dominant narrative is maintained by emotive statements.

The dominant narrative of the primary science teacher lacking in knowledge was identified by Ben, who knew this story from his time as a secondary teacher. In the transcription of Ben's first interview I could identify several examples of the dominant narrative but by the second interview he had reflected on his position, identifying that 'it seems I am a little obsessive about this' (see section 6.4.2). Justine said taking part in the research 'was really good because it makes you think', but there was no evidence of any change in her views as a result of being involved. I learnt a great deal from working with Justine about myself and my views, and I would not have learnt as much without engaging with her science life story. Justine's life story demonstrates that it is possible to take up science and become successful without formal science qualifications, though this success is not without personal anxiety. She demonstrated also the power of the elite; whispering that, even though she leads an influential primary science initiative, 'she was waiting to be found out '(see section 8.2.1). The influence of belief on knowledge is clear in all the biographical chapters and there are many reasons why beliefs are accepted (section 2.3). The dominate narrative is an example of context-related acceptance (section 2.3.3) but Stephanie identified an alternative interpretation of the dominant narrative, namely; that knowledge was only needed if the teacher was not able to learn alongside the children and to say, 'I do not know' (section 7.4.2). This demonstrates a type of courage or bravery rather than lack of confidence. There are other examples in the literature (see Table 2) that questioned the dominant narrative including the HMI who identified that primary science was 'one of the positive achievements of the National Curriculum' (section 2.6.2).

Primary science has been a game (Bourdieu, 1990)**,** told in many segments across time, where different rules (curricula) have existed (DfE/WO, 1989; DfE 1991; DfES 1999; DFE /QCA, 2004; DfE, 2013). Gadamer (1975) identified that the game also plays the players so the patterns and rhythms of primary education, such as the influences of broader policies and drivers (such as Ofsted) intended to determine what primary education should be like, influence the experiences of the children and their teachers. Research has reinforced the dominant narrative of knowledge and confidence to ensure it has remained in public and the government vision. Also, there have (also) been changes in the game, as the curricula evolved, for example**,** the first National Curriculum (DES/WO, 1989) identified the role of science as being for personal development, to understand society and for future careers. Science education was to enable pupils to 'use ideas in unfamiliar situations' (DES/WO, 1989, 4.1, p. A4). By 2000 the curriculum instead identifies science education as: *being needed for economic development supported by a deep-seated conviction by learned societies and government of the need for a pipeline of scientists* (The Royal Society, 2012; RSC, 2010; DfE, 2013; RSC, 2014) *without which the economic development and life as currently known was at risk.* The inclusion of 'the pipeline' provides the dominant narrative with a tangible outcome that poor teacher knowledge results in pupils not wishing to become scientists (see section 2.5). Research, questioning this position (Salzman, Kuehn, and Lowell, 2013; Xie and Killewald, 2012), identified other reasons for the leaking pipeline, unrelated to teachers or teaching, but the narrative of the leaking pipeline is strong and, although degenerative (Lakatos, 1970), like the paradigm itself, shows little evidence of being unseated.

Therefore, in answer to the first question: There is evidence to challenge the paradigm that states primary science teachers' lack knowledge and confidence. The evidence to sustain the idea that poor teacher subject knowledge and confidence leads to poor pupil perceptions of science is not conclusive. In addition, I have presented some evidence that questions aspects of the research methodology (that was) used, and which has contributed to how primary science is understood in literature and reports.

I will now examine the second question, still accepting that all the questions are and have been linked throughout.

10.3 The contribution of auto/biographical narrative enquiry

- What contribution can auto/biographical narrative enquiry make to illuminating problems, and or possibilities, for primary science by engaging with the lived experiences of a sample of primary science educators, with reference to their own learning lives?

This question could never have a simple answer and will now be examined. Working with others has challenged my previous position and, initially, I found it very hard to disengage from my objective stance to science education. The methodology I selected enabled me to examine a new perspective (Mishler, 1986) and, because the life-stories were not decontextualized, they produced a variety of meanings for, and understandings of, primary science. As identified previously, these case studies could have been amalgamated around themes, but then I might never have escaped from my positivistic science stance. There are several different perceptions of science taken by these science educators; the realist, the empiricist and positivist approaches can be found. I have not examined these in detail here as aspects were identified within the biographical chapters. This decision was taken for ethical reasons, to prevent caricatures of the participants, who are diverse human beings. Instead I have looked at the issues of effective teachers and border crossing. I then examine my own learning (Whitehead and McNiff, 2006) and the role of narratives in this learning. I finish this section examining the role of the models I developed as a result of the auto/biographical methods selected.

The findings from this work were not only about similarities but also about differences. This is important because these science educators could all present a session at the same conference, sharing their view of primary science with teachers, and yet each would portray a different version of successful practice. This suggests there is little consistency in approaches or practice, which could prevent primary science education from moving forward in a consistent way.

10.3.1 Effective teachers

I have learnt a great deal by working with these successful educators and the auto/biographical approach has illuminated for me both problems and possibilities. I now appreciate that the dominant narrative of primary science influences teachers in different ways, as the narrative presents what is in actuality a very diverse group as a uniform one. The way that the successful science educators dealt with issues they identified in primary science also varied. Peter thought a good primary science teacher would be someone who found the subject fascinating and who wanted to 'shine, set a light in the eyes of the pupils' (section 9.3.1). Peter also believes that teachers have to get the pupils involved in arguing about what they have observed or made to happen, 'it is that fermenting of imagination and of argument which matters'. Peter does not have a simple view of science or science education.

Stephanie believes that successful science teachers learn alongside the children, they do not stand back but instead take an approach that enables children to 'learn to be,' which is about autonomy, responsibility and whole person learning rather than 'learning about' (McWilliam, 2009). 'Learning about' science involves a more mechanical type of learning, where personal meaning is lost (section 7.4). Stephanie feels passionately that effective science teachers can learn alongside the children, even if they had failed at science in secondary school. Furthermore, she believes that they could come to love primary science. She shared an example of science identity transformation, where learning science with the children placed the teacher in the role of a facilitator, not director, and enabled the children to ask questions and to follow their own motivation. McWilliam (2009) argued that teachers should be 'usefully ignorant' and help learners not to fear 'not knowing'. Stephanie considers 'learning to be' is most important for the 'big group', who do not have their own motivation or identity with science initially**.** The teacher who acts, as a meddler does not recognise 'ability' and does not label children and can therefore promote a love of science for all.

Justine and Ben have very different ideas about effective teaching, with Ben disliking those that 'peddle nonsense' (section 6.4.2) because he believes in one science and correctness (Ziman, 1978). Ben's example of an effective teacher had, 'an amazing ability to generate a classroom atmosphere that just delivered on every level. There were kids, totally engaged - they were hanging onto his every word from the start to finish of the lesson' (section 6.4.2). Yet Ben also has a need for teachers to demonstrate 'wow' activities (section 6.4) because he believes that motivation is a key to children accepting a science worldview.

Justine conversely detests 'wow' activities because 'it is all noise and not understanding, science itself is the wow' and through undertaking science activities the world makes sense to children (Section 8.3.3**).** Justine's example of poor teaching was about a teacher who talked to the children rather than letting them experiment themselves (section.8.3.1). Justine suggested that**,** if the teacher had operated as a meddler rather than sage (McWilliam, 2009), she might have identified whether the children had developed an understanding of the structure of the world of falling objects, and why, some parachutes remained in the air longer than others. The children could have begun to reason, with the teacher's help, about this phenomenon. Then the lesson, where a great deal of preparation time had been invested by the teacher, might not have been judged as 'pointless' by Justine. Justine's most effective teacher had 'masses of stuff' and enabled the children to reason and gain an insight into the structure of plants**.** I now accept that the hegemony of science is very powerful and presents a certain model of the world, but I have come to understand that even within primary science there are many ways of seeing.

Working with these science educators and considering the debates concerning the role of the teacher, and what counts as effective teaching in primary classrooms, challenged my 'doxa' (Bourdieu, 1999). This study also made me challenge designations that previously I would have accepted; such as 'primary science teachers who lack confidence'. Acceptance that these teachers exist ensures actions that maintain the dominant narrative, for example, the attitude of 'get them to GCSE by lunch time' (PSTT), 'find specialist teachers instead of generalists' (The Royal Society, 2010), and 'provide more CPD' (RSC, 2014)**,** have all perpetuated the existing beliefs. In examining this issue, I suggest the question that should be debated is whether the 'knowledge and confidence' dimension**,** is the only explanation of why teachers are not teaching science? The literature and the biographical sections for me identified other issues: Could it be that teachers lacked ideas that work? (Appleton, 2003). There are also other reasons why some teachers do not teach the subject such as: other curriculum requirements, lack of senior management support and a lack of curriculum time (CBI, 2015, Wellcome trust, 2017).

10.3.2 Border Crossings

I learnt a great deal about science as a type of culture (Whitehead and McNiff, 2006), by working with these successful educators, but it was Stephanie's 'big group' (section 7.4) who made me question the relevance of current style science lessons for all children. Stephanie was interested in those children 'who are going to live and experience life because of science' (section 7.3). She wants science to support their understanding of the world because, for her, science is the world. She asked whether science currently was being taught in such a way that met the 'big groups' needs.

Ben also identified the needs of different children, when he used the 'not every child' argument when discussing aspects of science practice, but Ben believes science is not for the less able (section 6.5). He is the only science educator I interviewed to challenge the view of 'science for all children'. As a child who struggled in primary school, I found this aspect of his thinking alien, particularly with his inclusion of the 'wiring of brains' demonstrating the influence that neuroscience is having on education (Busso and Pollack, 2015). Ben's stance brings both scientific and ethical challenges, as the notion that there are brains that are wired in a 'particular way' could lead to the categorisation of children. This stance, supported by in-depth research into the influence of neuroscience, suggests 'that neuroscience discourse can promote reductive and deterministic ways of understanding groups might be conceived of as holding *deep, static and unchanging properties'* (Prentice and Miller 2007, cited by Busso and Pollack, 2015, p.172): This goes on to affirm, 'once less able, always less able'. Ben's assertion that there are children with brains which are wired for science influences his belief about attainment and ability, and if he had been my teacher, I might not have taken science further.

Justine demonstrates a grumpy stance with those who do not open the door to the world for 'little scientists' (section 8.4.1) because they are restricting the children from experiencing a science worldview. For Justine, science is in all things**;** science provides explanations and creates meaning for the world in which she lives, and science explains the world as it is. The problem is that this world of science involves children thinking differently, particularly in the abstract concepts of science (Wolpert, 1998). It is difficult for children find these patterns without a tour guide to help them within this world of science. Yet Justine also expressed concerns that if children were left to their own devices, some might not build the bricks of knowledge or develop the skills required (Figure 2) and 'end up nowhere', because their understanding and that of science are not aligned.

These discussions made me re-examine my understanding of the differences between enjoying science; valuing what science brings to society; and those children who cannot accept science or who science does not accept. As identified in Chapter 3, modern culture has been assimilated and moulded by a view of science (Olson, 1983) and while Western science is the dominant culture, this worldview is not the dominant view of all Western children, some of whom 'are lost to science'. The idea of being lost to science, concerned Justine and Stephanie. Peter reflected more on the issues of education selling the pupils an inaccurate vision of science. Ben identified that science was not suited to all children. As someone who found science fascinating, I had to question these different ideas and the narrative of 'border crossing' seemed to make some sense to my new understanding of primary science teaching (Mulholland and Wallace, 2003; Aikenhead, 2006). The border crossing is where science education is like crossing into a foreign land because the ideas of science differed from everyday beliefs. It was Stephanie's P.E. teacher, who, by becoming a science convert, suggesting that 'science is wonderful,' made me think about border crossings. She had taken an initial position stating 'God's truth'; (section 7.4.1), when she was told she would be the science leader. Stephanie's discussion about her P.E. teacher established how science transformation, or crossing into the world of science, might happen. There were echoes in other places, where a science worldview was not accepted, for example, when Justine said 'Just wake them up - make the world interesting, because it is interesting **'**; Justine demonstrated how she could not understand how teachers, children or parents could not accept a scientific worldview. Justine has crossed the border and become assimilated into science.

Peter shared his unique view of science which was informed by his time as scientist. As a result, he has *a science* rather than *a science education worldview*. Peter is aware of the challenges of science in a classroom and acknowledges that trying something new requires courage. Peter is passionate about pupils doing science in school, getting them involved and responsible, rather than just recipients' (section 9. 3.2), but he believes 'when you release children's imagination and inventiveness you get all sorts of things happening.' Peter said, 'I think the future is to channel that into areas where they will, first of all, learn that science is like this and will be involved in it.' As a result, Peter's view is not about a border crossing into science but rather that science is not what science education suggests it is. This was one of the challenges of this work, but also the opportunity for my own learning. I can accept Peter's view which involves all children and promotes learning that puts the learners in charge.

10.3.3 Personal learning about knowledge and narratives

Whether or not the world began with a Big Bang, it began, and it is stories of all kinds which create and re-create other worlds. I acknowledge that the current story influences how observations and ideas are fashioned and how powerful these stories are to their creators. Changing science stories is not a simple process and is understood in different ways, as a type of theoretical anarchism (Feyerabend 2011), revolution (Kuhn 1972) or research programme (Lakatos 1970). This is also true of the story of teacher confidence in primary science. Working with these life stories brought me into many worlds: Justine's world contains empirical science, where the knowledge of observable things confirms scientific theories. Justine's science lesson with flowers is a reminder of the value and requirement of infrastructural capital (Vladut et al, 2015) (section 8.3.1) and facilitated an opportunity to examine again the idea of ontic dumping (Feldman 1987) which had helped me to clarify aspects of the SKC. Ben favours a need for 'proper' science and scientists (section 6.5.2) and has a distrust of any other viewpoint. This view made me re-examine many of my ideas. Peter demonstrated the complexity of science from his background as a scientist but suggests we have made primary science 'too ambitious and misleading' (section 9.4.2). Through his story, I re-examined the differences between science education and the sciences. Stephanie asserts that science is about responding to questions with another question and this made me look again at pedagogy and how to bring meaningful learning to all children (section 7.6).

10.3.4 The world of truth and catching rain

Truth is an obedient servant (Goodman, 1978), and is found in many places. As stated, I would not have come to understand so much about myself and my story without both these stories and the published research on science, some of which I now challenge. The research I question involves the researchers making up and filling in (Goodman, 1978) by disregarding data that did not fit: for example, disregarding the number of teachers who expressed a confidence in science (Beggs and Murphy, 2005); or minimising the 44% of teachers who did not have a science background but whose science was sound (Harlen and Holroyd, 1997) (section 2.6). Initially I questioned the objectivity of primary science education research but, as I continued to work with the successful science educators, I was unconvinced that curriculum expertise was a concrete entity that exists in time and space; but that instead it was an abstract concept composed of many facets. Adopting Charles Sander Pierce's belief that an object is anything that can be thought or talked about, and my growing appreciation that the science educators talked about primary science in different ways, made me wonder again about the diversity of teachers, classrooms and pupils and how this might indicate that primary science is many objects, each different. While a biographical approach cannot identify universal certainties, if they exist, it has provided me with a richer and more detailed understanding of the situation. In order to examine the dominant narrative, the life stories of successful educators have been used as referents.

The life stories were agreed by the participants. They have cogency and, as separate stories, I believe they offer insights into primary science. At the beginning of this work I stated that I was not intending to find 'truth', but I was using the analogy of placing buckets to catch rain.

10.3.5 Returning to examine the rain in the buckets.

The rain caught in the analogous buckets enables an acceptance that knowledge is different within different worlds: whether the sun moves or not depends on the place from where it is viewed. I acknowledge that 'Scientific activity is determined not just by what we believe, but also by what we want' (Rosenberg, 2005, p. 182) and that within one world there must be specific ways of obtaining knowledge. This process in science and science education is called *verification,* even though it is fraught with difficulties related to objective observations and the world of the unobservable. In the realm of stories and narratives the process is called *verisimilitude* (Bruner, 2004). A story can have the feel of life and become so real that it could almost be touched, while other stories lack this believability. As a result of this study, I have come to accept that the process of meaning-making requires four aspects working together, namely; the personal style and biography of the person, their presupposition and motivation, which are both influenced by others and their social world [which includes Bourdieu's (1990) concepts of Capitals], and which are, in turn, influenced by the public policy in the particular domain of knowledge. These ideas came from trying to make sense of the different participants' presuppositions and resulted in the depiction of a range of influences on knowledge creation. This included knowledge existing in separate domains in the HVSK model (Horizontal and vertical structures of knowledge), which came about as I began to challenge my previously held belief that science was the only true way of knowing. (Figure 14 where both are presented side by side).

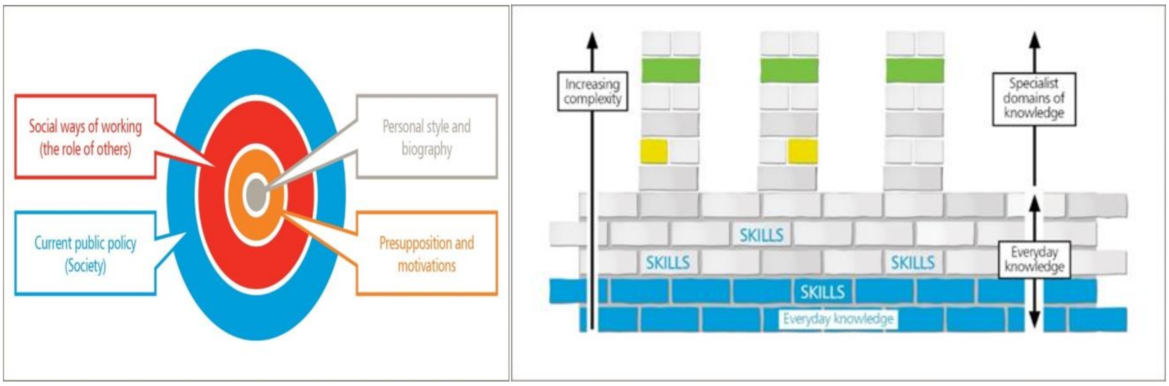

Figure 14: The HVSK and the SKC

There could never be one 'truth' to fall into the bucket but as I discovered, with help, the buckets were useful in explaining the integrity of each participant's story. However, as was shown, there are always multiple, complementary explanations; one of which is that the sciences and scientists are not value neutral and for me science is not what I thought it was. Through working with these successful science educators, I came to understand that everyone develops their own knowledge, building their own Horizontal and vertical structures of knowledge (HVSK) using their SKC.

Peter, for example, exists in both the vertical physics community and the science education community, but he is not a teacher. As an educator can only support the teaching of science by using his physic knowledge. Yet his geography teacher, who taught him about authentic activities that 'came alive before one's eyes' (section9.1.1), and the lecturer who by developing a few topics in detail, taught him about courage (section 9.3.1). They both helped Peter to add some important bricks into his horizontal wall of knowledge. Moreover, their approaches to teaching have been added within his vertical knowledge structures. Peter's life in science has been influenced by all sectors of his SKC and has given him a perspective that science education should be more like the sciences and therefore less misleading for the pupils.

Ben's vertical and horizontal structure of knowledge was created from a community that values knowledge and the elitism of science, but he is also now slightly uncomfortable with this (section 6.

4.2.). His early teaching experiences in physics created some behaviours that he modified when he became a primary teacher. His SKC was influenced when he lost his love, adventure and passion for science in secondary teaching. He found it again teaching primary science: 'It is just something about the way children react. It was like an adventure all over again,' (section 6.3), and he believes 'that children understand that science is exciting.' His motivations changed with this new change in phase, but his presuppositions have remained more static. Ben also added to his science education vertical structure by working with other consultants and ATs, enabling him to share his experiences with classroom teachers. His SKC was influenced by his education, family and working with others and has resulted in a belief system that is very different from Justine's.

Justine's early education has influenced her vertical and horizontal structure of knowledge, with her vertical structure having a specialist English knowledge column, because of her degree and interest in poetry; she can picture learning and make images using language, a skill I lack. The child on the beach and the child on the train promotes visions of science that very much endorse an evolutionary explanation of the science (section 4.2.3). The horizontal and vertical structures of knowledge related to science have been added later in life and there is evidence of assimilation in her approach to science (section 8.5). Justine was not a science person at school and did not understand the periodic table or an amoeba. The narratives she uses, and approaches adopted demonstrate the traditional curiosity captured in the *child as explorer* view of science. Yet there are contradictions: for example, the role of the teacher within *Frog Marched Discovery*.

Stephanie's vertical and horizontal structures of knowledge continue to be built on a need for science to make sense, to involve people in the science she fell in love with. This results in supporting teachers so they might not relive 'the fear of science' (section7.4.1) that comes from a knowledge-based science curriculum. Stephanie's SKC shows the strong influence of others; she works with many teachers providing the type of support that she received herself. Her presuppositions are that there are many different types of knowledge and skills, but there is a belief that science is how the world is structured (section 7.3.2). Stephanie's example of effective science teaching is teaching that engages non-science types and has the power to create love and affection for primary science. Stephanie is clear that for the 'big group', science is about love, stating 'and notice I use *love* not *understand*'.

For all the participants, science fulfils a psychological need and their biographical knowledge (their experiences and life as educators) influences their understanding of science. Love and enjoyment are important and the feedback mechanism between the recalling of enjoyment and remembering the substance of the learning, is acknowledged (Solomon, 2013; LeDoux and Brown, 2017). This issue could be the subject of further research. I still love teaching science, but I teach science now as one of the ways to knowledge, not the only way. I end this study challenging the dominant narrative (Lunn, 2002; Ofsted, 2011).

I recognised (See section 5.1) that auto/biography has many forms and approaches. I decided that my approach would be to enable the participants to tell their stories and then for them to identify what was important. The slash (/) was significant because my biography influenced the interpretation, analysis and how I presented the biographies (Stanley, 1992). The late addition of Whitehead's (1987) stance made me examine again what I know, and how I can affect change. By having to constantly challenge what I knew, and why I held such views, also altered my presuppositions. In order to make sense of these changes, I began to examine again what was knowledge and how it was formed. I suggest that a mixture of auto/biographical and personal reflection brings rich detail to the complexity but is not for the faint-hearted. Whitehead and McNiff (2006) would accept auto/biographical work within their framework as they look for inclusiveness not approaches that divide. I will complete this study with some suggestions for future practice.

10.4 Implications for teacher education and primary science

My final question was:

- What might be the implications of the above for teacher education and primary science, including the initial preparation but also CPD of science teachers?

I have three main recommendations which all concern knowledge in some format. The first concerns the use of the models of knowledge creation, the second is the role of others, and the final one is concerning the scientific viewpoint of the world

10.4.1 The models of knowledge creation

The creation of the SKC model that contains psychological, social and rational elements was useful in the analysis of the participants' stories. In unpicking science education through the eyes of participants and their life stories, I came to realise that defining science as rational and different from other forms of knowledge (the basis of Bernstein's vertical and horizontal model) does not lead to a realistic understanding of the sciences. Although this was my own understanding of science and the sciences at the start of this study, as demonstrated by my naivety recorded in the shell collecting vignette at the start of Chapter 1. The Bernstein model did not acknowledge the social world and yet the life stories demonstrated the importance of this aspect of knowledge creation. The reformulation of Bernstein's model into the Horizontal and vertical structure of knowledge (HVSK) model was an attempt to include a pluralistic view of knowledge because not everyone knows in the same way. The creation of the SKC was needed because of the complexity of life.

Both models could be used to support initial teacher education students in gaining an understanding of their biography, perceptions, presuppositions and motivations, as for these influences their current position. Many different theorists and theories can be used within the frameworks: for example, Lortie (1975) on how biography influences teaching; Bourdieu (1990) on types of capital and habitus in the SKC, and fields and habitus in the HVSK, and Bruner (1996) on conventionalizing efforts or the compromise between the established and the possible. Without individuals unpicking the different aspects of their SKC and examining the different domains of knowledge which have influenced them, each with their own 'particular gaze', the world tends to focus on the established, side-lining the possible.

Recommendation 1: The SKC and HVSK models should be used as a starting point to discuss knowledge creation in initial and continuing teacher education.

10.4.2 The role of others

The case studies and the resulting SKC also identified the importance of others and was influenced by Heidegger's (1962) ideas of 'Dasein' (section 3.2.1) - that a person's 'Dasein' is affected by what others think, say and do. I believe there might be a link between the 'Dasein' and a doxa (Bourdieu, 1990) as the case studies demonstrate the importance of social society and the role of others. For example, Ben gained recognition because of better than expected National Test results. However, Ben might never have left his classroom if negative feelings at school had not made him take a different fork and become a consultant (section 6.3.2). Stephanie's science advisor was very influential, teaching her the rules of the game and developing her science capital (Bourdieu, 2004) (section 7.2.1). Justine had several influential mentors: those who originally encouraged her to work outside the classroom running workshops (8.2.1); the supportive mentor who brought her into a university setting, helping her to understand the knowledge of science. This endorses the evolutionary definition of knowledge, i.e. that it comes from others and not only from the senses (section 4.2). Justine's current team continue to support her in the same way that big teams work together in the sciences (section 3.3.2) using their established ways of working. One of Peter's 'significant others' does not appear in his biographical material for reasons of anonymity but is highly influential in the primary science field and helped him with primary science. Without their support he might not have progressed so far.

I used the analogy of a river to describe my learning life. Inevitably, others have influenced the flow and direction of this river. My supervisors have, at times, provided a book, a question or a paper that resulted in the appearance of a sink hole, challenging my previous knowledge of how science should be taught. Human behaviour is not a simplistic chain of: A happens, so therefore B occurs**,** and many people can experience similar events, but the outcomes will differ. In the examples shared, the participants learnt the 'rules' and how to 'play the game'**,** from those who already knew. This led to those educators being recognised by the wider primary science education community. Those 'others' helped them understand the field alongside the game (Bourdieu, 1990). Within these original rules of primary science, the successful science educators have created some modifications that they now share with other primary teachers. Too often teachers are left without support but there should be a requirement to link CPD with long term engagement and the guidance of a significant other.

Recommendation 2: Opportunities should be provided for teachers and student teachers to be supported in science by significant others so that their development occurs within the classroom as continuing professional development throughout their careers, through a deliberately constructed practitioner-expert community.

10.4.3 The scientific viewpoint of the world

The other significant aspect of the SKC was that it revealed the importance of the presuppositions that informed the participants' grasp of the nature of science and their understanding of knowledge creation or epistemology (Whewell, 1847). Peter holds a hypothetico-deductive interpretation of science where theories are constructed by human minds and need falsification not generalisation (Popper, 2002), as demonstrated by his work with the circuits (section 9.2.2). Peter also favours activities that enable ideas to be checked against the evidence to see if they work, rather than expecting learners to make generalisations from sense data alone (Driver, 1993). Peter does not hold a simple view of the sciences and believes activities like 'cookie mining' enable the creativity that science education requires in order to make it authentic (section 9.3.2).

Stephanie believes that practical work should test learners' scientific ideas and requires the teacher to act as a meddler not as a sage (McWilliam, 2009). Previously I had not considered the role theories play in observations, or that my physics teacher translated observations into theory, making it seem as if I had made the discovery which began my enculturation into science. Ben positions himself on the side of absolute knowledge and his approach exhibits a strong element of 'public performance' (Scott, 2008, p.53): a performance that aims to lead the learners, specifically the more able, to a scientific viewpoint (section 6.4). These more able children can accept Ben's view of science and become encultured into the world of science. Justine's approach is more inductive and empirically based, viewing children as 'little scientists,' exploring the phenomena for themselves. This stance requires observations to be objective and facts indisputable (Driver, 1994), leading to the interpretation that science will grow steadily, which is not what actually happens (Kuhn, 1962).

As a result of examining these different presuppositions, it seems imperative to support both teachers and trainee teachers to understand science from a pluralistic position and to begin to examine their own presuppositions. They should not be expected to accept science education's view of the sciences or the resulting science worldview identified as the legend (Kitcher, 1993) [section 2.5]. Part of my learning has been to challenge my understanding of rational science and to accept the significant role of narrative in science. In order to understand many of the new ideas I had to go back to the history of science, and stories of previous discoveries, where I found that science is a subject full of explanatory stories. After working with successful science educators and listening to their stories of children for whom science is not for them, I now believe science could be a foreign world (in an anthropological sense) to them, but also a possible repository to be raided for useful knowledge skills and stories.

Throughout this work there have been examples of stories and narratives as ways of knowing (sections 2.1; 2.2; 2.4; 4.1; 9.3). If research suggests that science education is alienating some learners (Archer et al, 2013), perhaps adopting a storied approach might also empower learners to see science as a subject they could empathise with (Gilbert, Hipkins and Cooper, 2005). This is not new as Gilbert et al.'s**,** work with Maori schools suggests a story approach is inclusive. Others have suggested a narrative-based pedagogy would provide learning that was meaningful and not forgotten as quickly as traditional teaching methods (Avraamidou and Osborne, 2009). There are some dangers in such an approach, particularly if the narrative portrays the sciences in a stereotypical way or if it continues the narrative of an all-powerful science. There might be challenges from professional institutions and from teachers like Ben, who might suggest that what was taught was no longer science. A narrative based approach might support learners to cross the border into science (or attempt raiding parties) to provide learning that has a context that is meaningful. I particularly like the idea, identified by Aikenhead (1997), that science knowledge could be viewed as one idea among many and that children who hold alterative views, not a science worldview, might be able to take what is useful from science by learning how ideas were accepted and why, providing access to knowledge and skills.

In the future, I would like to encourage children, and their teachers, to identify with the stories of the sciences and come to understand the problems and the challenges that are inherent in the discovery and understanding of science.   The sciences have a history of adventure, hope, and passion and these adventures can be told in simple story form. As the participants all value practical activities, included within this approach would be 'activities that work' (Appleton, 2003, p. 16). By adopting such methods, children could be encouraged to use Peter's 'imaginative creativity' to solve problems, and science education could also become the 'wow' that Justine envisages, but this could be experienced within the worldview where the sciences do not reign supreme.

Recommendation 3: Instead of expecting the 'big group' to change and accept a science education view of the sciences, research should be carried out into the value of approaches that can be used that help all children to raid the science repository (Aikenhead, 1997) without enforcing a science worldview upon them, but still providing access to the stories of science.

10.5 Conclusion

In examining the river (Mink, 1970) from an aerial view, I have learnt that I am not the same person who naively undertook the SPACE project or became an advisory teacher. I am now aware of how little I understood about the construction of scientific knowledge and I understand the feeling, identified by Siemsen (2014) that it is like having the proverbial rug pulled from beneath your feet to have one's confidence in the absolute rationality of science removed. For example, I never questioned how Newton could have observed how bodies moved in a straight line without inertia (Matthews, 2000) and was unaware that Galileo's experiments could not be replicated (Naylor, 1974). My beliefs were unsophisticated and perpetuated the legend of science (Kitcher, 1993).

I have suggested that a causal relationship between knowledge and confidence is too restrictive as there are more nuanced reasons for what happens in science education. Yet I am aware that this idea that poor knowledge and low confidence are the key factors in determining what happens in primary science education is *considered real*: I hear colleagues regularly impart this to would-be teachers. I suggest that all people have limited knowledge of the sciences, as knowledge changes and there are too many aspects of the sciences for any one person to specialise in all its many branches. This reminds me of an experience in a school where reception children were discussing animals with their teacher. One child shouted out 'starfish have beaks!' At this the rest of the class roared, 'No they don't' - looking to their teacher for confirmation. I was sitting at the back of the class and when the teacher turned and said, 'that lady there will know'; I was happy to respond, 'I do not know but shall we find out!'

The idea of the all-knowing teacher is irresponsible as why should I, or anyone other than an asteroidean specialist, know about starfish (now called sea stars) and how might I guess a five-year-old would know or remember the beak fact? Admittedly, not knowing something as a teacher feels dangerous in the current education climate. It is easy as a specialist to hide behind the superior nature of your knowledge, but even Ben did not know about 'the beak'. Justine would have worried that everyone else would have known but Stephanie would have accepted that there are ways to find out and got on with it. As a result, I believe science education needs to look again at research into a 'learn alongside the children' approach that was identified by Ben and Stephanie, whilst acknowledging the concerns, expressed by Justine, about teachers needing to get children to where they wanted them to be. This, therefore, is the fourth recommendation.

Recommendation 4: Primary science education should avoid the idea of the teacher as the deliverer of knowledge. This conversation could begin with the sharing of biographical material, allowing further debate in this area.

I am conscious of how much more I need to learn as there is no single version of a story, each person identifies with different aspects. Alheit (1994, p. 288) makes a thought-provoking point that: "We have more opportunities than we will ever put into practice; our biography therefore contains a sizeable potential of "unlived life." I began this work as a naive realist and end as a critical realist, accepting that it is through abstraction, idealisation and narrative that knowledge is created. Working with the stories of successful science educators and using other stories of science, from Gell-Man naming quarks, to Bohr's use of his son's shoplifting to explain the behaviour of particles (Bruner, 1996), has led me to new understanding, something that I think the stories of science can offer to all.

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Appendix 1.

My Journey which took Bernstein's (1999) Vertical and Horizontal Model of Knowledge as a starting point and resulted in the Sphere of Knowledge Creation (SKC).

Introduction

This appendix details how my ideas changed as a result of undertaking an auto/biographical investigation with successful science educators. This appendix contains information on the journey I underwent which resulted in the creation of both the *Horizontal and Vertical structures of Knowledge* and the creation of the model called the *Sphere of Knowledge Creation (SKC).* The appendix details the iterations that were undertaken until a form was settled upon that supported both the biographies of the successful science educators and aspects of what I had read. The appendix is written in a chronological format, but at times my research moved backwards as well as forward. I begin by discussing the start of the process.

1.1 My initial thoughts

I began by interviewing several successful science educators and instead of the '*unitas multiplex'* (Feldman, 2005, p. 5.) which means *unity in diversity*, I found *diversitatem diversitati quae est secundum* or *diversity in diversity*. I worked with the transcripts and multiple interviews, struggling to understand how their narratives could link into one model of knowledge or a single philosophical position. The opportunity to discuss the science life stories of these successful science educators did, however, make me question everything I thought I knew. I realised that both myself and some of those educators held a view that science education and science were the same thing and that scientists were people with a science degree. This latter view I discovered was the accepted definition of a "Scientist" (Xie and Killewald, 2012).

I started this study holding a positivist position, but after reading philosophers such as Heidegger, 1962; Feyerabend,2011; Harre, 1986 and Rosenberg, 2005, I began to question my understanding of scientific realism. Consequently, I read a greater range of writers, for example, Gadamer (1976); Rorty (1979); Hacking (1983); Bruner (1986); Bakhtin (1993) and Longino (2002), in order to find a position that explained the way that science educators viewed their world. This process resulted in examining several diverse theorists, some of whom I have identified above. These individuals had elements of theory in common although their wider body of work often differed. In some cases, for example Bruner, their later work contrasted with their earlier work and clearly, they were on their own journeys of discovery. The apparent diversity of thinking of the successful science educators led me initially to examine the different definitions and ways of categorising knowledge.

Bernstein's (1999) *Vertical and Horizontal Model of Knowledge* was taken as a starting point in order to examine the ways knowledge can be classified. I was drawn to this model because Bernstein accepted a dichotomous view of specialised and everyday knowledge, but he also highlighted the value and uniqueness of scientific knowledge, both of which suited my understanding of knowledge at that time.

Janette, one of the participants who I interviewed three times but whose biography was not included in the final thesis, identified science as *a type of sacred knowledge*. This led me to the early work of Durkheim (1892) who examined the belief systems and knowledge creation of religion and the difference between the sacred and the profane. The idea of science as sacred knowledge was also documented by Solomon (2013) who suggested that science had once been sacred but was now commonplace. In some sociological writing (Moore and Muller, 1999) the dichotomy appeared to revolve around the value, or otherwise, of non-scientific ways of knowing. I found the inclusion of different dichotomies a common inclusion in the writings of many different authors and Chapter 3 was built upon these dichotomies. The commonalities in the writings of some very diverse theorists, was useful as it provided a structure to some of my early work on classification of Knowledge which resulted in the HVSK. One such example was Rorty (1979) who adopts a pragmatic approach, but who valued the working practices and congeniality of scientists. However, Boehm and Peat (2000) would disagree that that is how science is perceived by those scientists whose ideas are not part of current mainstream thinking.

The diversities of the theorists, alongside the viewpoints of successful science educators, made me question how so many different viewpoints could co-exist. This might seem naive, but I had previously accepted a scientific realist position and had never questioned this approach. I was aware that scientific ideas changed, and that science was not always right, but that was not the same as recognising that science is not cumulative or that science itself was not the miracle subject, I accepted it to be (Kitcher, 1993). This is important because in the interviews some of the participants made similar statements about how science is not always correct, and they acknowledged that scientific ideas can and do change. Yet these stated viewpoints about science did not prevent them from adopting a cumulative, science as a miracle narrative. This is not unusual as Lyotard (1984) identified the false impression that scientific and technical knowledge is cumulative and this is never questioned.

1.2 Accepting the Vertical and Horizontal model of knowledge

I initially accepted a vertical and horizontal framework, but as the successful science educators discussed how they thought children developed their understanding, the more I questioned my previous beliefs. After seeing for myself the immensely practical nature of Bernstein (1999's) two-mode system created, I realised that I needed to revise this model, partially because it was founded upon the idea of science as a special form of knowledge. Bernstein's model clearly had advantages as it was able to develop both categorisation and formation of knowledge within the single model. However, the vertical element of the model did not fit with what the successful science educators discussed. Furthermore, it did not explain what I understood from working with scientists and engineers as part of my 'day job' running a STEM hub.

Bernstein's vertical structure was depicted as a pyramid with an emphasis on scientific modes of learning. Moreover, it stated that other subjects had a weaker grammar. This approach reinforced the understanding of science I had held earlier in my life but did not link to a pluralistic view (Longino, 2002) that was becoming my way of explaining the world. By envisioning the vertical dimension in a way that enabled different subjects to have their own ways of working, and by not identifying science as the only form of specialised knowledge, resulted in a model with separate columns for each domain of knowledge. I also found that the inclusion of both creation and categorisation of knowledge in one model was not effective. As a result, in order to reflect the diverse views of the science educators, the acquisition of knowledge was separated from the categorisation system.

The categorisation, at the everyday/non-specialist level, of knowledge as a state, a possession or activity (Fabian, 2014), appeared to reflect the successful science educators' views. Consequently, the horizontal element of Bernstein's model was adopted but it was in the specialised areas of knowledge where things become more complex with the creation of new ideas appearing less straightforward. The biographies of successful science educators demonstrated that science for them was about finding 'Truth'. There were issues revolving around the Science educators' concept of Truth. Although, as time passed, I realised that the application of Truth was really an examination of scientific realism, where the successful science educators discussed what was in the world and what was true about it. Bakhtin (1993) was against a simplistic definition of Truth and criticised the assumption that if two people disagree, at least one of them must be wrong. This challenged my previous understanding and Bakhtin was instrumental in the development of the Sphere of Knowledge Creation as will demonstrated in section 1.4. of this appendix.

This debate about Truth and what is in the world, resulted in reading about controversial aspects of science, like quarks, that cannot be seen (Hacking, 1983). This was a significant aspect of this study for two reasons. First, I had never heard of ideas such as, "entity realism" (Hacking, 1983), or had to address my misunderstandings of science. Secondly, I saw that the dominant narrative in primary science education revolves around a lack of subject knowledge resulting in lack of confidence of primary science teachers. Primary teachers are not required to understand quarks but are expected to teach aspects of science that are no longer accepted as correct by scientists. I spent a long time contemplating whether the things that physics postulates (quarks for example) were real or just constructs of the human mind. If all scientific knowledge was a construct of the human mind and nothing was real, then the dominant narrative in primary science becomes irrelevant. In grappling with these questions, I began to unravel my understanding of science and my own educational development in order to answer the question posed by Whitehead, 'How do I improve my practice?' (Whitehead, 1989, p. 51.)

This was a challenging process which led me to question: Why some things are accepted as knowledge and some are not? I also questioned why some types of knowledge were considered to be more important or valuable. It seems to me that society has a perception of science as an important form of knowledge and has elevated science to the highest form of knowing (Hacking, 1983). This primacy of science was questioned by Aikenhead (1996) who asked why the narrative promoted by the Eurocentric view of science takes precedence over other forms of knowing. As a result, I began to question the "miracle of science" approach, which alongside the work of Durkheim made me question the idea of science being set apart from the world as something sacred and only possible because of *organic solidarity* (Durkheim, 1893) and the high level of division of labour. This recognition of a division of labour was identified by both Gopnik (1996) and Plotkin (1997) (see section4.2.3) but explained in different ways to Durkheim, who wrote before the universal acceptance of evolution.

1.3 Working within in a vertical structure

Initially the new format for the vertical structure of knowledge allowed for different forms and types of knowledge to work together and for different views to exist at the same time within different communities. This categorisation system did not explain how knowledge was created, so my next iteration was to picture what happens within these vertical structures that enabled knowledge to be created.

After examining the biographical material, the first depiction envisioned the individual at the centre as they act within the world as it currently is. However, it became clear that some individuals also play a role in creating new knowledge. Using the biographical interviews, I saw that within community individuals quite naturally share ideas and thoughts. They do this by using theories and ideas that support the current accepted knowledge, i.e. they are acting *in* the world of knowledge as it is. The narratives of their domain inform the way they view the world. However, the individual is also able to act *on* their world. I started to picture the individual at the centre of the S1 creation of knowledge (Holton,1973) as shown in figure 1.

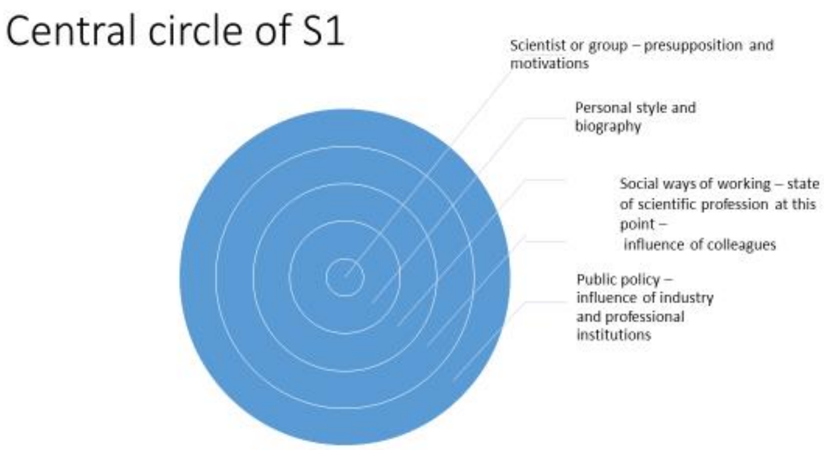


Figure 1. The central, inner world of Knowledge

I used the ideas of private science, here denoted as S1 (Holton, 1973), and the influences on the creation of scientific knowledge as discussed by Olson (1983). Olson suggested that the intellectual certainty of the sciences is taken for granted, and that few people appreciate how modern culture has impacted upon and moulded science. Holton also presented ideas about what he identified as the "private world of the scientist" and how it was very different from the public knowledge of science portrayed in wider society. I worked through the biographies and tried to understand how individuals said they operated within their community of science education. Initially I developed the model from the perspectives of teacher educators and then verified them using the biographical information of famous scientists. I examined all the influences that were present in the biographies and identified that the community of practice, the vertical silo, influenced the individuals in a variety of ways.

At first, I thought that the foremost feature in the model was that the individual was influenced by the dominant narrative within their domain at this time. Evidence for narratives playing a role in the creation of knowledge was clear in the histories of the sciences, for example, the original depiction of the atom as a solar system. Narratives have always influenced science and were presented in the work of Kuhn (1962), as periods of normal science. Lakatos (1976) defined them as research programmes that were accepted by the science community at that time. After listening to the science educators' stories, and reading both Kuhn and Lakatos, I wondered if within a vertical structure, a new local narrative had the power to alter the dominant narratives. For instance, if the scientists' personal narratives influenced the change in understanding, for example, from phlogiston to oxygen or from Newtonian physics to Einstein's theory of relativity. Lakatos (1976) suggested that the explanation of how scientific knowledge was constructed changed with Kuhn and the story of the accumulation of external truths became a fairy tale. I found many of the examples of narrative change existed within the field of the history of science. However, these were not widely discussed before Kuhn's (1962) *Structure,* perhaps because the dominant narrative was different. Further reading of philosophers, such as Latour (1989), transported me into debates which questioned whether phlogiston had ever existed, or if bacteria could be said to exist before Pasteur named them; or if science was even a subject at all. I think this is where Whitehead's "living theory" was a helpful frame, as I examined the *diversitatem diversitati quae est secundum*. I had moved from a positivistic approach to decide that critical realism was more in line with how I viewed the world**.**

1.3.1 The model in detail

After listening to the science educators very different views, I began to picture that within the centre, the individual was bringing their presumptions and motivations to the sense data and therefore acting *on* their world. In the process I was moving backwards and forwards between the interview data and what I was reading. The examination of Reed's (1992) work on the influence of the environment was an important aspect and began to provide a limited explanation for the different viewpoints that the science educators explained in their interviews. I accept that the world is complex, and that each person will identify with only certain aspects of this data. However, I also acknowledge that their ideas can alter as individuals change their aims and interests after grappling with the things the material world hurls at them (Pickering, 1995). I was a prime example of this change. Pickering (1995) was one of the first writers to identify the unusual number of influences on the development of scientific knowledge. In Pickering's view, work culture, time and place, all influence knowledge production. Furthermore, he challenges the idea of the isolated scientist struggling with only nature. I began to believe that the intricate and powerful knowledge produced by scientific inquiry is a cumulative product of multiple instances of individual knowledge. But I agreed with Longino that such knowledge, "Can be understood without reference to social interactions" (Longino 2002, p. 575). My research with the science educators showed me that there can be many who work within any particular field who hold varying presumptions and motivations, and that only 'outsiders' might imagine that all those in that field behave as a stereotype.

The interviews suggested that the personal style and biography of the individual influenced this inner ring and the history of science seemed to support this. For example, in some quarters it is believed that Newton's work was influenced by his desire for power, political influence and authority and that these needs influenced the decisions that he made. His belief in God also affected his theories and views, but his life story, including watershed events, like the second marriage of his mother and the plague, provided him with opportunities that resulted in his later success. The isolation of Einstein's early life enabled him to create his theory of relativity and his personal style and circumstances meant the social working of the profession at the time has less of an influence on him. As a result, his influence *on* the world was greater than the influence of his community upon him. Although his work was published in 1905, he had to wait until 1921 for the Nobel Prize, demonstrating that the dominant narratives in science take time to change.

The personal biography of the individual or group is also affected by the social ways of working, the equipment, 'what we all know' and the other colleagues working within the field. After reading Collins (1985), it appeared to me that some decisions reflect what the core set of those working scientists know and believe. Public policy and the professional institutions also inform these micro-social aspects. The interviews also showed how public policy influenced primary science and that all these factors influence what is known. There were many unanswered questions, so I then began to look at the sociological setting in more detail.

1.3.1 The sociological setting

The creation of knowledge is not rational or social, but both. Moreover, the sociological setting within which this individual's community is situated impacts upon the knowledge creation. It is not just nature, but it is nature and the dominant narratives together. However, the current ways of working, and the equipment in operation, will all influence the observations made and what those observations mean.

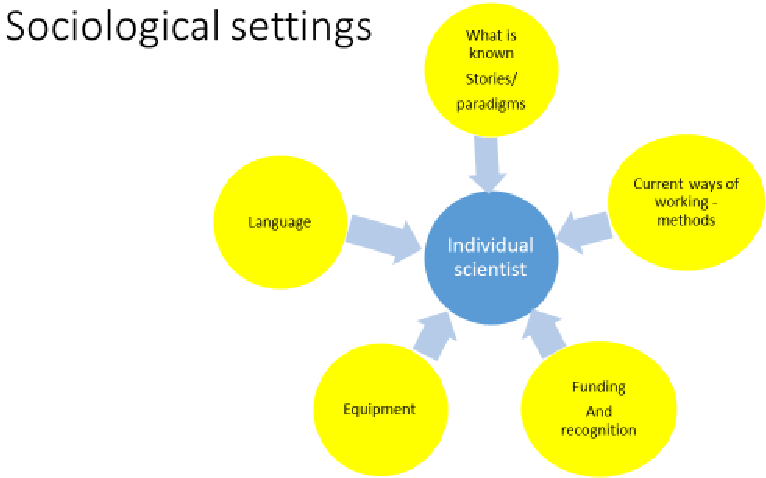


Figure 2 the sociological setting

Without funding and recognition, the individual science educator will not progress and without speaking in a way intelligible to others inside the scientific community, their work will not move forward. I think the same is true of what is adopted as knowledge in any area of learning. Academic work must be communicated in an accepted style and format and cited by others. Unless this is the case, regardless of whether the work contains knowledge, that knowledge is not valued by society, at any given time, and is therefore not knowledge (Bohn and Peat, 2000). All these sociological factors help shape the knowledge creation model but that does not mean they *are* the knowledge creation process. All the sociological settings are part of the S1 or the private face of knowledge production. Society undoubtedly influences the private element of knowledge production. Bloor, (1983) suggested that society distorts the knowledge by macro-social influence. For instance, where factors, such as social class (Barnes and Shapin, 1978), affect the individual's beliefs. The famous case studies from within scientific research facilities (Knorr-Cetina,1981, Latour and Woolgar, 1979) did not support this assertion but they did recognise that the public view of scientific practice was flawed.

1.3.2 Wider influences on knowledge

Consequently, I questioned whether these were the only forces at work. After considerable thought, I reached the conclusion that whilst, the community at large influences the private knowledge function, there are wider issues that also carry weight. For instance, historical aspects have a bearing upon what society is interested in funding, as do professional viewpoints at any one time. At this level, these still have an impact on knowledge creation, but they are beginning to be outside the direct knowledge creation process. Knowledge may be created but it may not be used or agreed to be knowledge. As seen in Figure 3, the political, historical, cultural, professional and funding aspects influence the knowledge creation process.

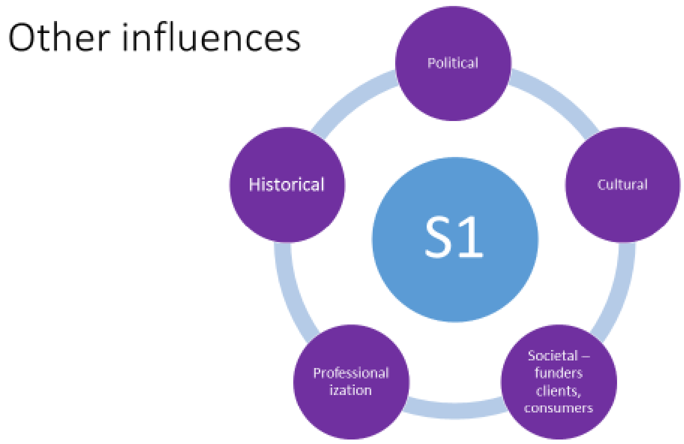


Figure 3 the wider influences on knowledge creation

These wider influences were discussed by Pickering (1995) as well as Olson (1983) and I found these aspects interesting and relevant today. Historically the atomic view of matter has resulted in money invested in large hadron colliders. The particles from space were initially used for experiments, but then the quantity available of cosmic rays for research meant they needed to be created 'manually'. As these facilities are expensive, only some groups of scientists can use these facilities, leaving other scientists, who hold different views, without access to funding or the ability to test out their ideas (Bohn and Peat, 2000).

Another aspect to consider related to culture. In the same way that some modes of knowledge have hegemony, some culture's ideas appear to be valued more than others. Culturally the Aboriginal society views knowledge as created by humans, the living and the non-living environment (Reed, 1992). This is very different from the powerful Western scientific model, although some theories contain the influence of non-humans (Latour, 1998). I thought about how the non-human aspects of curriculum, discussed by the successful science educators, Stephanie and Peter, identified several cultural issues. For example, how a certain time or resources can all influence knowledge. These ideas reinforced my need to try to understand all the issues involved.

It became increasingly clear to me that the way aspects of society are structured also influence the attainment of professional status. Not everything is valued in the same way and what is valued often maintains the status quo (Bourdieu, 1990). As a result, certain types of learning, or the demonstration of skills, ensures that some elements are valued above others.

1.3.3 The model

The model I created put the individual at the centre. The knowledge they create is individual, but is influenced by the community within which they are located. Knowledge creation begins with the individual's unique contribution. This is embodied in their creative imagination and their distinctive view of the world. These in turn give rise to actions which sustain the community, just as those same actions are enriched by the community. It is through these influences that new knowledge is created. Some of this knowledge is likely to be accepted by the community, but undoubtedly some will not. Clearly, the views of the community at any particular time will influence what is accepted. Knowledge cannot be freed from history, social trajectories or context. Feyerabend (2011) suggested a pluralistic view is the most appropriate one for science, for unanimity of opinion is more suited to the Church. Feyerabend (2011) thought that the loss of intellectual autonomy results in the acceptance of one perspective as the way to the 'Truth' resulting in blindness to truths offered by other approaches.

Initially, I viewed the model as that depicted below. This model was created by linking the ideas of Holton (1973), Olsen (1983), Pickering (1995) and Feyerabend (2011) but it became clear that some of the elements appeared in more than one place and a simplification was required.

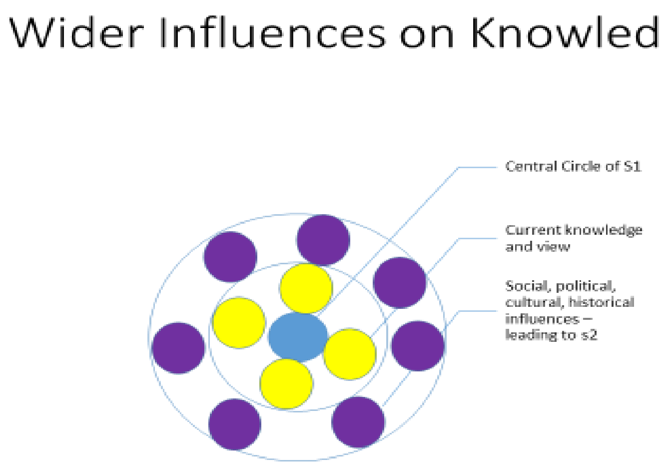


Figure 4: How the community of knowledge influences knowledge creation

I began to question the function of professional bodies and political forces after interviewing both Stephanie and Justine as they discussed how these groups influenced the decisions made by the specialist group at the centre. Pater was very influential in this process, listening to Peter demonstrated how, over time, some aspects of specialist knowledge made their way into the public domain. Moreover, the facts are translated from the specialist language within which they were created, into a language suited to the new audience.

1.4 The changes to the model

As discussed above, initially I thought that the narrative that society accepts, and the motivations and presuppositions of the individual would be central in the creation of knowledge for everyone. My initial format for the Sphere of Knowledge Creation placed motivation and presuppositions of the individual as the inner circle (figure 1) and yet watching my grandchildren grow, I noticed that while their environments were similar, their personalities and interests were not. (I have worked with primary teachers in an advisory capacity for more than thirty years and have identified similar differences in groups of teachers.) Therefore, it should not have been surprising that the biographies of the successful science educators also contained differences, which were linked to their biography and personalities. Whilst the dominant narratives are important, the personal style and motivation appeared to be central.

The science educators' presuppositions were informed by their personal style and motivation. Everyone can attend the same taught session and read the same materials, but there are inner influences on what knowledge they accept and understand. Indeed, personal style and motivation appeared to alter the way the successful science educators viewed their world. As time went on, working with the biographical materials, it became apparent that personal biography was central to the way the science educators developed their knowledge.

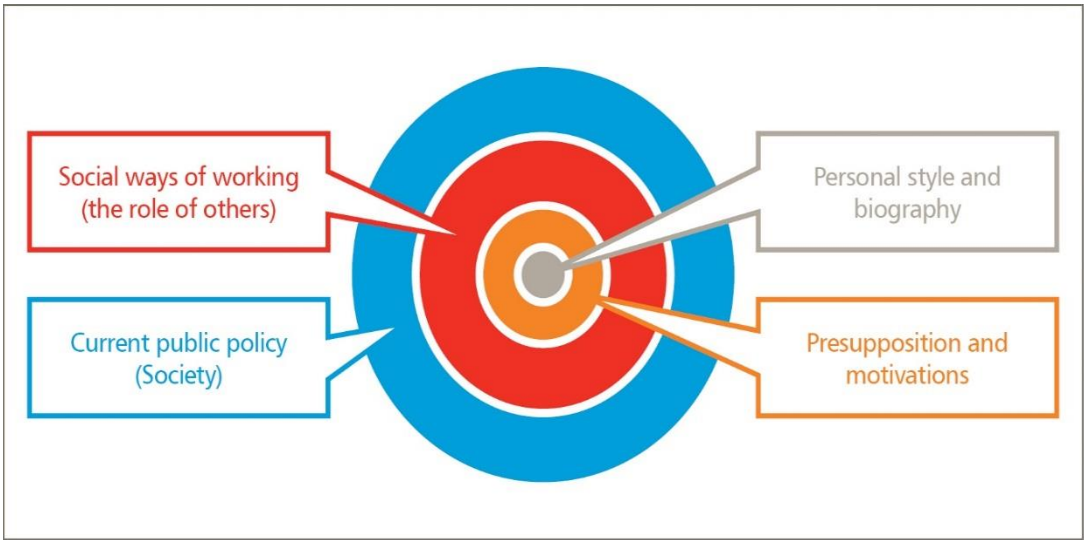
Personality was also a key influencer on knowledge, in that in order to view the world in one way, to challenge the accepted and create something new, requires tenacity and courage, accepting that status quo comes from a different personality type. Jannette was told at fourteen she could not do chemistry because only boys did chemistry at her school. Janette was determined to take chemistry and was supported by her parents, who had to pay for her exams. She says she was persistent, pig headed and keen to prove her teachers wrong.

The personal style and biography of the individual influence heavily the presupposition and motivations that are developed. Although all the successful science educators had been identified as being "good at science", there were some great differences. Justine did not like science at secondary school and took up science later in life, being identified as successful in her thirties. Ben instead was a keen *'scientist'* from the start. For some of the participants feeling, or being identified by others as “clever” by obtaining success in science at an early age, was linked to later competency in science (Eccles and Wigfield, 1995). I was a child who struggled with writing and found science far easier than other subjects. Peter also was successful in science and recounts being given a sixpence for being the first to solve a scientific problem. Justine’s success as a teacher led to working as a consultant.

Biography can also influence knowledge and outcomes in a less positive way. For instance, Justine just never got the point of science at school; she did not actually get to do the science activities. Although this did not prevent her from being able to pick up science later, the early lack of understanding has made her adamant that certain approaches need to be adopted with children. Bakhtin (1993) was a useful theoretical friend, unlike Vygotsky (1978) whose approach is from the point of view of the significant other who scaffolds the learning. Bakhtin’s approach focuses on the individual – how the individual can influence their environment and their own learning. Vygotsky’s approach is favoured by teachers as there is a clear and significant role for them outlined in the Zone of Proximal Development, namely what they (the learner) can do with their help, and there is an emphasis on the other (teacher) creating the need. Bakhtin instead saw the individual as the driver.

All participants mentioned how they would not have achieved as much without the significant influence of others, but the influence was not necessarily a step by step incremental approach, but rather to provide advice and guidance not related to a specific aspect of learning. Those others might be work colleagues who supported and challenged. Again, the influence of personality and presuppositions influenced the impact of these others. Bakhtin (1993) suggested every person is influenced by others in an inescapable and intertwined way and therefore no voice can be thought of as isolated. He suggested that without others it is not possible to understand ourselves. The impact of others in the biographies resulted in the final format of the model. Moreover the role of others appeared to be an important part of the model as aspects of the social ways of working. It is also clear that I still have much to learn in this area. The circles are continually changing as the influences of everyday life, events and activities alter the individual’s SKC. This non-static nature of learning is not a novel idea nor is the idea that the life we live is only part of the possible life that could have been lived (Bruner, 2004).

Figure 4 The SKC in its current iteration



I have argued that understanding is located in complex inter-relationships comprising of individuals and their communities, but is also embedded within the dominant narrative that is prevalent at any one specific time. The belief systems of the educators, who form the central element of this work, influence Primary Science Education. As identified in Chapter 10, their own views are influenced by their 'story of science' but the successful science educators go on to carry this influence further by the roles they play within the primary science community.