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FOUNDATION PHASE LEARNERS' CONCEPTS OF THE NATURAL WORLD

by

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OCTOBER 2018

DECLARATION

I declare that this is my original research for the purpose of the thesis, *Foundation phase learners' concepts of the natural world,* and that all sources I have used or quoted have been indicated and acknowledged by means of complete references.

____________________________ ________________

Francois Naude Date

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“Be ashamed to die until you have won some victory for humanity.”

- Horace Mann

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ABSTRACT

This study aimed to find out how early grades learners express their thinking about some of the themes in the school science curriculum. In a cross-sectional, qualitative study, with data from Grade R and Grade 3 children at a primary school in Soweto, it was evident that the learners had not advanced in their thinking beyond naïve conceptions of vitalist biology ('living and non-living objects) and observational astronomy. The research was undertaken to fill a gap in the knowledge of local children's emergent concepts of the natural world and how these are elicited in the classroom. It is a problem space because natural science is not explicitly included in the foundation phase curriculum. It only occupies a marginal, and often 'concealed' space, within the *life skills* subject strand known as ‘beginning knowledge’. I argue that this exclusion, along with the absence of suitable science content teaching (and pedagogy) in initial teacher education programmes, need to be addressed in research. I argue that it is important for student teachers and teachers in practice to know as much as possible about how children see the natural world. With such knowledge, curriculum and instruction can be designed to suit the children.

The study comprised two phases: interviews were conducted in informal discussion format after all the learners (n=53) had watched a series of classroom demonstrations. The second phase consisted of a smaller sample (n=20), when individual, clinical, task-based interviews were conducted about two topics, namely 'living and non-living things’, and 'earth, sun and moon'. The findings show that there is limited progression over the three-year period (from Grade R to Grade 3) of the participating children’s concept development. This study shows, also, that, although many of the participants may lack normative science concepts, they were able to reason sufficiently to understand some of the causal relationships in natural phenomena. But overall, the detailed analysis of the children's discourse and activities show that they need systematic instruction and language advancement to express their understanding.

The study was conducted as an exploration of conceptual change and the work of theorists in the field, such as Susan Carey, Alison Gopnik, Elisabeth Spelke and others formed the framework of the study. Science learning and conceptual change theorising of specialists such as Stella Vosniadou and Andrea diSessa complemented the literature framework. The analysis of the video and audio data were analysed qualitatively, coding and categorising the content, and selected data for discourse analysis. The research was conducted with an interpreter who could serve as back and forth translator for isiZulu, which was utilised by children and the interviewer in code-switching.

My thesis was that teachers are unlikely to invest in the science teaching in the early grades if they do not have a good understanding of what children's beginner knowledge is. I argue that teachers' apparent lack of knowledge of children's understanding of the natural world may be one source of the limited attention given to science education in the foundation phase. It may be that teachers' own knowledge of vitalist biology and observational astronomy is limited. The study concludes with recommendations for teaching of science in the foundation phase and also for suitable initial teacher education and for professional teacher development (in-service) training programmes. The question this research poses as a suggestion for future research is: 'How can some basic science concepts be woven into the curriculum of the entire foundation phase, integrating it with not only the life skills subject but also the language and literacy, as well as the mathematics subjects?' I argue that teachers need firmer conceptual knowledge of science as well as greater comprehension of conceptual development of science concepts in early-grade children in order to improve their pedagogy of science teaching.

Keywords: *Science education, conceptual change, conceptual development, vitalist biology, observational astronomy, primary school education, elementary school science*

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CHAPTER 1

OVERVIEW OF THE STUDY

1.1 BACKGROUND AND MOTIVATION

Teachers of the early grades of the primary school in South Africa usually do not encounter research on young children's science concept development in their pre-service education, or in professional development programmes. This may be because the school curriculum for the foundation phase does not emphasise science education (Kok 2017). The latter leads to a naïve understanding of the tenets of science among student teachers (Cronje 2015; Pretorius 2015). Abd-El-Khalick, Bell and Lederman (1998) point out that a relationship exists between teachers' views on the nature of science, and how they teach. There may be an underlying assumption that teachers will be able to incorporate the teaching of science concepts systematically into the life skills curriculum in the section referred to as 'beginning knowledge' (https://bit.ly/2Lm2qoi) in the foundation phase. Apart from the limited space in the curriculum, teachers also find it hard to teach science concepts, such as 'floating and sinking', which is a topic in the school curriculum, competently (Kok 2017). The reason for this is that foundation phase teachers often lack both subject knowledge (substantive knowledge), as well as knowledge of the nature of science (syntactical knowledge). In addition to the two mentioned limitations for teaching science, most teachers find it hard to explain, for example, the *concept* of density, although they may successfully present a demonstration. Learners may use terminology and even do some practical 'experiments' without grasping the concept. I argue that if teachers have some knowledge of developmental aspects of children's forming of science concepts, they may be better able to teach the (few) science topics in the foundation phase curriculum conceptually. However, if they do not know about the intricacies of how children develop concepts of the natural world, and what children's prior knowledge is, it is unlikely that they will be able to teach well and to integrate science teaching with the rest of the curriculum.

It is with this notion in mind that I decided to investigate foundation phase learners' concepts of the natural world as a possible contribution to early grade teacher's pedagogical content knowledge (PCK) (Shulman 1987). I reasoned that such a contribution would take note of research in science education, which has been at the forefront of studies about what Gardner (1987) refers to as the ‘cognitive revolution’. Science education research has been a leader in the field of conceptual development and conceptual change theory for the past four decades. Research on conceptual change in early grades science learning has been conducted in various parts of the world (see, for example, Vosniadou 2009), but very little has featured in South African studies, where high school science has featured more strongly in research. Rollnick et al. (2008); Lelliott and Rollnick (2010); and Ogunniyi and Rollnick (2015) are examples of such studies. I agree with Duit and Treagust (2003:1), who hold the view that “research on students' and teachers' conceptions and their roles in teaching and learning science has become one of the most important domains of science education research on teaching and learning during the past three decades.”

To contribute to the body of knowledge of the learning of science in the early years of schooling, I designed a study in which I could investigate a component of young children’s science concept development, with the aim of making this known to the teacher community – especially of schools where children may have had little exposure to science knowledge in their pre-school years. I posed the research question, framed by conceptual change theory (Posner, Strike & Hewson 1982; Vosniadou 2009) and planned to investigate what naïve concepts children in the 6-9 year age-group hold with regard to concepts in *observational astronomy* and *vitalist biology*, both of which feature in the foundation phase ‘life skills – beginning knowledge’ curriculum in the Curriculum and Assessment Policy Statement as it currently stands (Department of Basic Education 2011).

1.2 RESEARCH PROBLEM

1.2.1 The ‘beginning knowledge’ conundrum

In this paucity of knowledge about early grade children’s conceptual knowledge (or their ‘theories’) of the natural world, I identified a research problem. The supposition on which the formulation of the problem is based is that children enter school with views of natural phenomena that they have constructed from their experience in pre-school years. The problem is that teachers mostly do not know what this knowledge is. Researchers in the field of South African educational research do not know much either and are faced with the “learning paradox” (Bereiter 1985). Bereiter formulated this paradox of constructivist epistemology: The (unknown) complexities of prior knowledge on which new knowledge is to be constructed assumes that existing knowledge is 'prepared' for new knowledge. Yet, in my piloting discussions with teachers at the research school they suggested randomly what they thought children may have theorised about astronomy and life. There was no consistency in what they had mentioned. My sense was that they had not given it much thought before. I reasoned that this may be why many foundation phase teachers that I have encountered approach the teaching of science with the assumption that they need to impart 'new' content knowledge, with little attention given to the nuances of early scientific 'literacy' or the concepts and theories that young children have formed by the time they enter formal education (Kok 2017; Magnusson, Krajcik & Borko 1999; Duschl 2008). I would say that the likely reason for this approach to science teaching stems from a lack of understanding how children build their concepts of natural phenomena, compounded by the teachers' lack of science content knowledge (Magnusson, Krajcik & Borko 1999). In this problem space I found the 'gap' in the local literature and in the practice (Snow 2015) - the void in South African publications.

Thus, in this thesis I investigated the nature of foundation phase children's science concepts to address the issue of 'beginning knowledge' of science in the rather skeletal national curriculum of 'life skills' for the foundation phase. There is, according to Gopnik (2012) an urgent need for knowledge about how children in the first years of schooling conceptualise the natural world as a basis for further learning. Neither educational studies, nor the research field of cognitive development in psychology in South Africa has yielded in-depth evidence of what children express, be it linguistically, through tasks with objects, or through their reactions to science experiments that they witness, or their interpretation of content of books or electronic media content. I argue that this void poses a multifaceted real world problem; it may even be one of the reasons why there is nothing more than a somewhat haphazard foundation phase curriculum for science teaching; there may simply be too little understanding of what children know and are able to learn and how these could be integrated across the curriculum of the foundation phase.

1.2.2 Sociocultural perspective

The problem reaches further than the issue of descriptive knowledge of children's concepts, because the children of this country grow up in diverse social-, economic- and cultural-, as well as linguistic settings; I have not encountered research about how these factors feature in learning science in the early childhood years. Developmentally, it is known that children’s theorising develops through stages (Carey 2009, 1985; Vosniadou 2008; Gopnik & Meltzhoff 1997; Astington & Gopnik 1991; Gopnik & Graf 1988; Gopnik & Wellmann 1992), yet there is little available data of what happens, for example, in pre-school years in nursery schools and day care centres and nothing about science in the homes, except for middle-class homes and their presence on the internet. I also argue that teachers and researchers should know more about the possible ‘stages’ of conceptual development that are typical and how children’s learning may differ in a South African ‘township’ context (Spaull 2013).

1.2.3 Expectations of the intermediate phase curriculum

In addition to what has already been argued in the discussion of the problem so far, the expected knowledge that the intermediate phase curriculum assumes about what children actually know by the end of the foundation phase is of great concern. There is an observable gap between what is expected of learners in the foundation phase and what they are expected to know when they enter the intermediate phase. Keeping in mind the theory of Vygotsky (1978) on conceptual development, which proposes that learning in school comprises the meeting of ‘spontaneous’ and ‘scientific’ concepts through mediation (by teacher, tools, such as media, first-hand experience, with semiotic guidance), the limited part played by science learning in the foundation phase is of concern to this study.

Although the foundation phase curriculum includes some teaching of concepts in life sciences and astronomy, there is hardly any explicit reference to teaching of concepts of chemistry and physics. Mindful of such discrepancies, one could ask if the foundation phase can then prepare learners sufficiently for learning science in the intermediate phase. This study presupposes that the national, regional and international comparative studies of science knowledge and skills of older learners, such as the various TIMSS studies (Reddy et al. 2015), reflects that there may be missing building blocks in science learning on the one hand, and the unrecognised developmental capabilities of young learners on the other hand may go unrecognized. Evidence of extremely limited science knowledge of South African learners is pertinent in the report on the Trends in International Mathematics and Science Study (TIMSS 2015). TIMSS instruments are a measure for assessing what learners have learned in mathematics and science in school by the time they reach Grade 6. TIMSS also

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captures background information on students, teachers, schools, curricula and official policies to allow cross-national comparison of educational contexts that may be related to student achievement.

A report from the International Study Centre of Boston College (Martin et al. 2012) confirmed that 10 countries namely Singapore, Japan, Hong Kong, South Korea, England and Wales, Taiwan, Finland, Belgium, USA and Russia are the most consistent in the global rankings as top in the global competition assessment above all their counter parts from other nations. South African learners performed well below average. A preliminary comparison of some of the top achieving countries' curriculums with the South African foundation phase curriculum reveals that the majority of these countries place greater focus on science learning in the lower primary school phase. This could potentially be one of the key factors why these countries consistently perform well in global benchmarking tests like the TIMSS.

1.2.4 Children as theorists

Yore and Treagust (2006) notes that the nature and extent of learners' understanding of scientific concepts and phenomena depend on key components of a science curriculum. However, one cannot design a curriculum in a vacuum that excludes psychological knowledge of learning and conceptual development. I argue that to design a science curriculum or plan a science lesson, one needs to know some basic developmental theories of cognitive development. More than 30 years ago already (before the wave of laboratory studies of young children started with methods of habituation studies and in neuroscience studies), research showed that by the time learners are taught formally in science classes, they already have idiosyncratic notions regarding science concepts and that these views are not aligned with the views accepted by the scientific community – they are naïve concepts (Osborne et al. 1983). These idiosyncratic concepts can have a significant effect on new learning as they could either support or impede the scientific conceptual development (Ausubel et al. 1968; Duit & Treagust 1995; Pintrich et al. 1993) as these views could be deeply rooted and could be impervious to traditional teaching. From contemporary developmental cognitive psychology it is evident that young children theorise their world (Gopnik 2012; Tenenbaum et al. 2011; Carey 2009; Gopnik & Meltzhoff 1997). Susan Carey has shown, already in her first major publication (Carey 1985) that there is a progression in what she later refers to as 'intuitive theories'. Along with theorists such as Gopnik (2012) and Spelke (2010), she sees children in their development as ‘makers of theory’, learning to adapt their theories as they experience/experiment and as they learn through cultural tools. One such tool is language, which forms a gateway to much of initial learning when they enter the world of symbolic learning (Henning & Ragpot 2015).

1.3 RESEARCH QUESTION, AIM AND OBJECTIVES

In the investigation about the ‘conundrum’ of ‘beginning knowledge,’ the research question that I addressed is about the naïve concepts children in the 6-9 year age-group hold. I asked, “What theories do children in Grade R and Grade 3 hold with regard to concepts in observational astronomy and vitalist biology?

The immediate aim of this study was to make the theories children hold explicit by way of the following objectives. In addition to studying relevant literature, I planned to:

1. Crystallise principles of design for an analytic instrument to interpret data about children’s concepts.
2. Explore children’s theories regarding observational astronomy and vitalist biology in classroom settings as well as interviews with children outside of a classroom setting.
3. Employ activity system analysis to interpret the findings.
4. Utilise the custom designed heuristic tool to interpret the theorising of the children.

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1.4 DESIGN OF THE STUDY

The research was designed to investigate the theories that early grade learners hold qualitatively, as a case study (Henning et al. 2004; Stake 2008; Yin 2013) with specific parameters. This type of design aims to gain a rich and descriptive understanding of how people construct meaning from their experiences (Merriam & Tisdell 2016). This research modality is typically employed when an exploration of a phenomenon about which little is known (Creswell 2007) in a specific context. Furthermore, the study was conducted as ‘practitioner research’ (Cochran-Smith & Lytle 2009), because I wished to investigate part of my practice as science teacher educator. I argue that foundation phase teachers need to ‘know the learner’ as part of their pedagogical content knowledge (PCK) as described by Shulman (1986, 1987) so that they can adequately design learning opportunities that would facilitate science concept development.

Various approaches to qualitative research has been developed and includes research designs such as basic qualitative research, phenomenology, ethnography, grounded theory, qualitative case study and narrative analysis (Merriam & Tisdell 2016). This study is simply designed as a qualitative case study. In the 'bounded system' of foundation phase children's expression of understanding of science concepts I recognise that their understanding is nested within a sociocultural and educational reality that influences the development of conceptual structures. For this reason, I use activity system analysis (ASA) as an analytical and interpretive device in addition to the tool I designed and which I have named the hierarchy of mental entities (see Figure 2.3). In planning the study, I decided that the participants should not only express their conceptual understanding through talking about natural phenomena, but should also be given the opportunity to see some (science) demonstrations of natural phenomena in classroom 'science shows' and also create and interact with objects in clinical tasks to explain their concepts.

I opted to include these science events and task-based interviews as modalities for data collection, while sampling children from Grade R and from Grade 3. I wished to obtain data that could generate insight into the participants' conceptual structures and delve into their understanding of natural phenomena, and ultimately my interpretation of their understanding. The reasoning for the design of the study, specifically the approach to data analysis, was guided by an overview of qualitative data analysis process as suggested by Miles and Huberman (1994).

The unit of analysis (Trochim 2006) of the study was foundation phase children's expression of their understanding of observational astronomy and vitalist biology. Generation of data occurred during two separate iterations of interviews at an urban primary school in, Soweto, Johannesburg. The full cohort of isiZulu classes in Grade R and Grade 3 participated in science demonstration classroom interviews as part of the first iteration of data collection. The analysis of this data informed the creation of task-based interview protocols, with randomly selected individuals from the Grade R and Grade 3 isiZulu cohort. Both data sets were translated, where necessary, and transcribed. The utterances and actions of the participants were analysed using inductive coding (Henning et al. 2004; Strauss 1987; Strauss & Corbin 1999) to reduce the data into coherent and manageable entities. In Chapter 3, I explain the design of the study more explicitly.

1.5 OUTLINE OF THE STUDY

I have opted to structure the report of this study according to the traditional APA style for doctoral and master's dissertations, which consists of five chapters. In this section I describe the layout of each of the chapters.

The first chapter describes the background of the study as well as the research problem. The research question, aims of the research and design of the study is also described in this chapter. The theoretical framework of the study is presented as part of a study of relevant literature in Chapter 2, focusing on theories of conceptual development and conceptual change as well as studies of children's learning of the two science topics I have selected for study. In the third chapter I describe the research design and methodology that I utilised to collect, reduce and analyse the data. I also focus on issues related to ethics in this chapter. The results of the data analysis are presented in Chapter 4, where the themes that emerged during the coding and categorising are explicated. Chapter 5 comprises a discussion of the findings of the study wherein I draw conclusions from the intersect of the findings and the theoretical grounding of the study. I also make recommendations in Chapter 5, and critically reflect on the contribution of this study.

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1.6 SUMMARY

This chapter discussed the research problem as it relates to the specific context of science learning in the South African foundation phase curriculum in a 'township' school. I set out the research question and associated aims of the study, namely to describe the conceptual development of children in the early grades of schooling as pertaining to the science themes of observational astronomy and vitalist biology. The research design, including the data collection and analysis, that I have employed to answer the research problem has been explained.

CHAPTER 2

SCIENCE LEARNING IN THE EARLY GRADES

2.1 INTRODUCTION: TEACHERS AND LEARNERS ALIGN

The central argument of this chapter is that for foundation phase teachers to teach science and to align their pedagogy with early grades learners' existing knowledge, they need to have some insight into what learners already know. In the parlance of cognitive developmental psychology (Carey 1985, 2009, 2011), this means that teachers should have some sense of children's *conceptual systems* of specific topics listed in the curriculum. In other words, they need to 'diagnose' children's conceptual development in some assessment format, before attempting to design lessons. The development that I refer to includes both biological development and the development of mental representations of concepts. To assist children in the learning of new concepts, teachers need to have some sensitivity for the nuances of the existing conceptual structures of the young learners in their class. This type of teacher knowledge is a notion described by Shulman (1987) as 'knowledge of the learner' which is an essential component of a teacher's pedagogical content knowledge (PCK). To put it in curriculum terms – I argue that as a first step in designing a work plan for a few weeks, as well as an individual lesson, the starting place is 'the learner'. This is, of course, not a new idea. Reform pedagogists in different times of the history of formal education have accentuated this beginning point (Langeveld 1960; Barnard 1859; Froebel 1885; Dewey 1956; Comenius 1887). Yet, in the time when young school-goers in South Africa struggle to cope with the demands of the curriculum, the dominance of 'curriculum cover and compliance' is noticeable in studies about foundation phase education (Radebe 2018; De Villiers 2016; Mabalane 2013; Graven & Venkat 2014).

Even though the curriculum propounds 'constructivism' as a principle of teaching and of learning, the pace of the curriculum makes it hard to truly find out 'where the learner is' before designing a work plan. From the first day of school children learn mostly new things and they are assessed in 'formative assessment' mode, but it is unclear to what extent individual learners are given support when needed. From a constructivist epistemology position, it is important for a teacher to establish which foundation has been laid by a child's historical interactions with her home environment and the social structures of the community. Encounters with the natural world in a child's everyday life are also important to take into account before attempting to build on this foundation with new concepts. Connections with what a child knows is fundamental to teaching (Caine & Caine 1991). I invoke the often-cited image of Vygotsky (1978) to illustrate this point of developmental readiness of a learner and the role of a teacher. A child is unlikely to grasp the 'outstretched hand' of a 'Vygotskian teacher,' attempting to guide the child through the *zone of proximal development* (ZPD), if said teacher does not comprehend the intricacies of cognitive and conceptual development; knowing how concepts develop in young children can give a teacher at the very least some developmental norm of how children form concepts (about the natural world). This chapter serves to explore some of the literature of early science concept development and the contextual factors that influence the development of these science concepts.

Many disciplines have long attempted to identify ways in which we can determine the state of a child's conceptual development. These disciplines stretch through the academic spectrum from philosophy and developmental psychology to neural imaging techniques and standardised testing, each exploring different aspects of the same phenomenon. What is important to this study is how the education community approaches this important aspect of the educational agenda, pertaining to the teaching of science in the foundation phase. The foundation phase curriculum in South Africa does not sufficiently frame how science should be taught to young children and includes very little formalised science topics, especially when compared to other disciplines such as mathematics and language and literacy. This is worrying, seeing that the Grade 4 natural sciences and technology curriculum expects of learners to have obtained certain science concepts during the foundation phase. This is further problematic because of the attitude most foundation phase teachers have towards the teaching of the life skills subject. Sheldon (2015) found that foundation phase teachers regard the teaching of the 'life skills' curriculum as a secondary priority and spend most of their time teaching mathematics and language. I argue that the scientific literacy of all South Africans could be greatly improved if the robust teaching of science is included in the foundation phase. Researchers in science education, such

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as Lavonen (2013) and Charlesworth and Lind (2010) accentuate early learning of science process skills as the ignition of the extensive process of conceptual change from naïve science concepts and intuitive theories towards normative, or scientifically accurate concepts of the natural world.

I further argue that teacher training institutions should also include the teaching of scientific literacy more prominently to equip foundation phase teachers with the knowledge and skills to teach science concepts. Foundation phase teacher training curricula usually include one semester module on science pedagogy over a four-year degree programme. The pedagogy is science content-based and in this there is no mention of post-Piagetian theories of conceptual development of natural phenomena.

In this chapter I will discuss some theories of conceptual development which will include “the origin of concepts” according to Susan Carey (Carey 2009) and the theory-theory of concept development as described by Gopnik and Metlzoff (1997). Since these authors introduced the notion of the ‘theory’ of conceptual development, many protagonists have been investigating its validity (Barner & Baron 2016), while others have discarded it (Rips 1995). This study specifically investigates the work that leans mostly to the side of Susan Carey’s work on the continuum of children’s development of concepts.

I hold the view that science teachers and educational researchers who work in this field can be placed in a quadrant of two themes in a matrix (Figure 2.1): knowledge of conceptual development (y-axis) and knowledge of science (x-axis), which can be used to classify how appropriate a teacher’s knowledge is to teach science.

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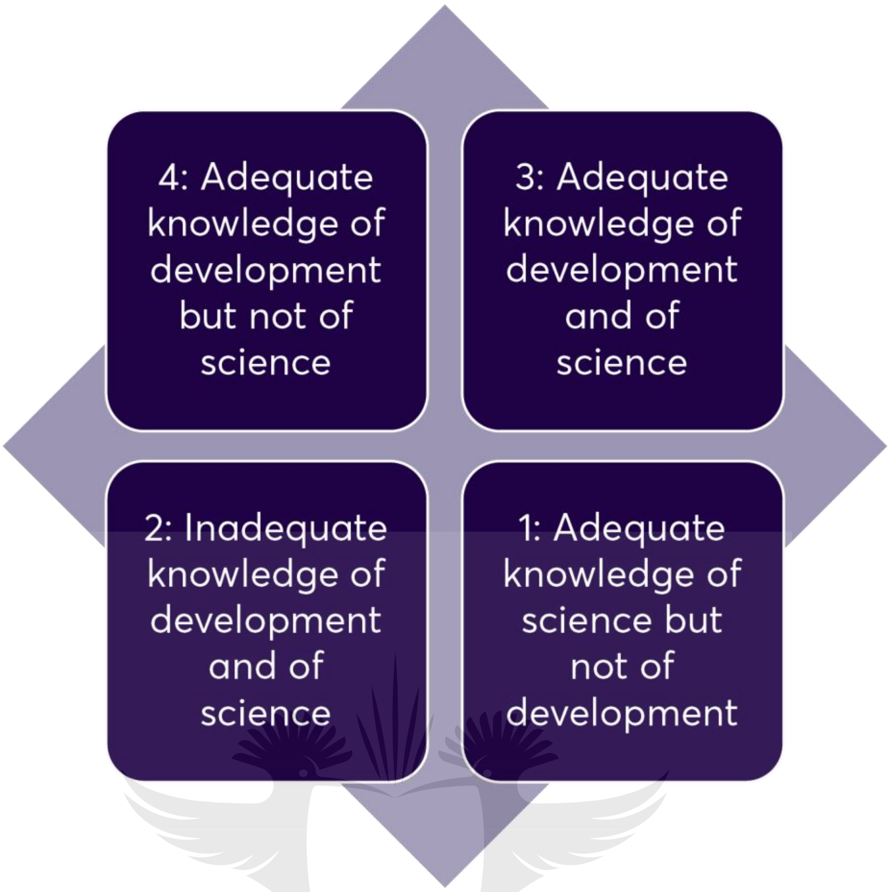

Figure 2.1: Knowledge of science and knowledge of conceptual development

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If one were to assess teachers on their knowledge of cognitive and conceptual development as well as their knowledge of science and the teaching thereof, I hypothesise, that one would be able to 'plot' a teacher in one of these four quadrants. I will argue that all science teachers should fall in *Quadrant 1* to teach science effectively. From what I have observed in numerous schools is that most science teachers in the primary school in South Africa fall in quadrant two and three. In the academic discourse of publication in South African journals and at conferences this is evident too. This might be the reason for the sub-standard science knowledge of South African children.

This chapter comprises discussion of a selection of the literature pertaining to conceptual change and the development of conceptions that children hold about natural phenomena. For now, I will broadly define natural sciences concepts or conceptions as a person's mental representation of a natural phenomenon. This definition holds many assumptions and requires a nuanced understanding of various aspects as described by a myriad of authors. Figure 2.2 is a heuristic devised to create a visual road map through the arguments that I posit in this chapter.

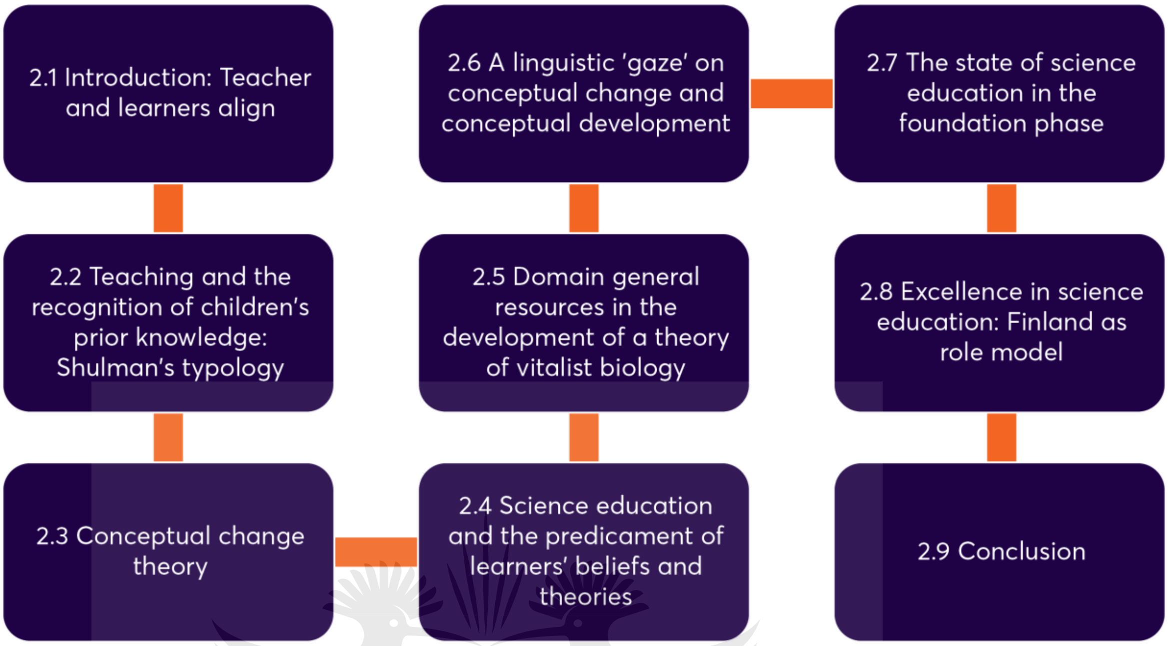

Figure 2. 2: A roadmap of the chapter

In Section 2.3 I discuss the nomenclature that is often used to describe the nuances of mental representations. The (cognitive) development of concepts as held by children in the early grades of primary school as well as conceptual change theory will form the core of the discussion. I first argue that science teachers should have knowledge about the cognitive structure of concepts that children hold about natural phenomena as well as some knowledge of the mechanisms involved in the change of these concepts. Here I invoke the writing of Shulman (1987), Carey (2009), and Barner and Baron (2016). Secondly I describe the processes involved in the acquisition of initial concepts and then the views of leading authors on the cognitive *mechanisms* involved in conceptual change.

As the first focus of the discussion in this chapter I argue for the notion that science teachers should have an awareness of the prior knowledge of the children whom they teach, before attempting to design a suitable teaching event.

2.2 TEACHING AND THE RECOGNITION OF CHILDREN'S PRIOR KNOWLEDGE: SHULMAN'S TYPOLOGY

Lee Shulman's typology of teacher knowledge (Shulman 1987) includes the often-cited notion of PCK which is defined explicitly as:

> (t)he transformation of subject matter for teaching occurs as the teacher critically reflects on and interprets the subject matter; finds multiple ways to represent the information as analogies, metaphors examples, problems, demonstrations and classroom activities; adapts the material to students' abilities, gender, prior knowledge, and preconceptions (those pre-instructional informal or non-traditional ideas students bring to the learning setting); and finally tailors the material to those specific students to whom the information will be taught (Cochran, DeRuiter & King 1993:264).

Before being able to teach others, a teacher needs a good understanding of not only the subject matter but also an appropriate way in which to teach/transform the content pedagogically. The problem is that to choose an appropriate teaching method, the teacher first needs to identify learner characteristics. This, in itself, is challenging. School classrooms are diverse in every sense of the word. But one aspect that is often overlooked by teachers is that to teach a concept to another person you first need to determine what it is that that person already knows about a concept. This is true whether one teaches an individual or a large group. These factors, among others, form the essential structure of most teacher training institutions' curricula. Comenius already wrote his *Didactica Magna* (Keatinge 1967; Petker 2018) in the 17th century, with the 'didactic triangle' as organising principle (Henning 2012), with teacher, learner and content as the three points of the triad.

Shulman (1987) argued for teaching that accentuates comprehension and reasoning, transformation and reflection. He argued that at the time of writing there were a multitude of studies that described effective teaching from a classroom management point of view but that there were few studies that describe how teachers manage ideas. More than 30 years after Shulman's article, the landscape of education research in South Africa remains similar

After several iterations of the national curriculum in the past 20 years there is still emphasis on the content that teachers have to teach but very little is said regarding the prior knowledge of children. In the instances where teachers are encouraged to determine this prior knowledge very little guidance is given on how teachers should approach going about gauging this prior knowledge.

In comparing the practice of student teachers to that of expert teachers we see where the students struggle with knowledge, comprehension and skills drawn from the collective understanding of the body of knowledge in teaching. A teacher's practice is a direct result of the knowledge or lack of knowledge. In an attempt to define the body of knowledge for teaching Shulman (1987) studied the practice of expert teachers and described the relationship between content and pedagogy in the minds of teachers. He identified the categories of the teaching knowledge base as follow:

- Content knowledge;
- General pedagogic knowledge;
- Curriculum knowledge;
- Pedagogical content knowledge;
- Knowledge of learners and their characteristics;
- Knowledge of educational contexts;
- Knowledge of educational ends, purposes, and values and their philosophical and historical grounds;

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Even though Shulman (1987) predicted that these categories will be refined, his work is still considered by some as the foundation of teacher education and these categories has remained relatively unchanged. He offers the following sources of the teacher knowledge base:

- Scholarship in content disciplines;
- The materials and settings of the institutionalized educational process;
- Research on schooling, social organizations, human learning, teaching and development, and the other social and cultural phenomena that affect what teachers can do;

- The wisdom of practice itself.

It then stands to argue that for teachers to be competent in teaching they will gain knowledge in each one of the seven categories mentioned above by engaging in practices associated with the four sources of these knowledge.

The knowledge category that is of particular interest to this study is that of 'knowledge of the learner and their characteristics'. More specifically, knowledge of the prior knowledge of the child. I argue that that this is the fundamental category and that it means teachers should have basic knowledge of conceptual change theory.

2.3 CONCEPTUAL CHANGE THEORY

The human phenomenon of learning through the use of signs and tools has been studied widely. The neural structures that can facilitate it are innate, although some, like learning to read, are 'recircuited' (Dehaene 2009) for this purpose and depend on instruction. It is also known that certain 'core knowledge' is already present in the infant mind and that this knowledge changes as life progresses (Dehaene 1997, 2009, 2011), depending on what is learned from the environment. Carey (2009) and other cognitive developmental psychologists such as Spelke (1994, 2011) and Gopnik (2012) have written extensively about the changes that happen in the cognitive structures of infants when they begin to respond to the world around them, forming and changing concepts all the time. What an adult knows just prior to the end of life is vastly different and more complex from that what is known in infancy. Even though it is possible to describe this change in knowledge, the challenge lies in explaining the mechanisms and cognitive processes through which these changes occur. Many developmental psychologists have dedicated their work to exploring the nuances of learning and have attempted to adequately describe the initial state of the human mind following birth. For the purposes of this chapter, I first describe what researchers write about innate knowledge of an infant before mapping the development of their learning.

Xu (in Barner & Baron 2016) argues that innateness has been 'pugnacious' in the field of developmental psychology as it poses the challenge of accurately characterising the initial state of infants' minds. It is difficult to determine what it is that infants know, what they are capable of thinking and learning and what kinds of 'knowledge monomers' are in place at or shortly after birth. Xu (2016) says that it would

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be near impossible to comprehend the nature of learning and developmental change if we cannot characterise the initial state. Most notably, scholars such as Piaget (1954), James (1890) and Quine (1969) have posited the initial state in various ways and have also proposed several stages of children's cognitive development. Most of the work of Piaget about stages of cognitive development is now widely called into question and a contemporary view of the initial state of the human mind comes from scholars such as Carey et al. (2015), Spelke (1994), and Gelman (2003), Gersten (1999), Sarnecka & Lee (2009), Dehaene (1997) and others. These authors, who propose that infants are born with certain core knowledge systems that have innate concepts at the centre of the developing mind of a child.

Such core knowledge systems are also evident in closely related species, suggesting that this knowledge arose early in the human ancestry and therefore has evolutionary survival value. Carey (2009) proposes that infants have a rich set of reasoning principles and core cognition systems in place by the age of one year. These core knowledge systems include innate concepts such as object, number, agent, causality, mind and space. Each system comprises a vast network of interrelated mental representations that allow the individual to 'recreate' the natural world in her mind. Barner and Baron (2016) explain that humans get to know their world by creating a 'copy' of the world in our minds. It is through mental representations of objects, occurrences, properties and ideas that experience is constituted. Being able to recreate the physical world in one's mind holds many advantages in that it allows for thought activity that does not require the individual to be physically located in the actual environment about which thought is happening (Gopnik & Meltzoff 1997). These mental representations are often prefaced in language in that single lexical terms, such as nouns and verbs, can hold a wide range of semantics that are often difficult to express otherwise. Language, from this view, serves as representative agent, apart from being a communicative agent. Barner and Baron (2016) argue that the interactions between mental representations and vocabulary give some explanation on how thought and language are related – much as posited by Vygotsky (1986). Nouns, such as leaf, water, bird, etc. immediately evoke a set of mental representations of objects, whether it manifests as images, sounds or feelings, or a combination of these, and creates a common understanding between individuals who are communicating via language. Verbs such as walk, beg, laugh, etc. capture the

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actions that occur during interactions. The wide range of mental representations are commonly referred to as concepts.

In the introductory chapter to the volume, *Core Knowledge and Conceptual Change*, the editors (Barner & Baron, 2016) highlight the challenges facing researchers in the field: Firstly, we need to describe the *initial state* of the human mind. Secondly, we need to explain how *new concepts* are acquired. Lastly, the *mechanisms* involved in constructing new knowledge has to be explicated.

In this section of the chapter I will attempt to address these challenges, as presented by some key authors in the field of conceptual development and conceptual change. I begin by clarifying some of the varying vocabulary used by the scholars of conceptual change theory to present some form of unity in terminology.

2.3.1 About 'concepts' and related terms

diSessa (2002) argued that classifying all mental representations as concepts is problematic because several diverse mental entities are involved during the changes that occur in humans' representation of the world. Several scholars in the field of developmental psychology have attempted to describe these diverse mental entities, which has resulted in a smorgasbord of classification systems. Such systems attempt to find some hierarchy of mental entities. Authors use different terminologies when referring to these initial mental entities. Such terminologies include ontologies (Chi 2008), beliefs (Hofer & Pintrich 1997), models (Vosniadou & Brewer 1992), theories (McCloskey 1983; Gopnik & Meltzoff 1997) and intuitive theories (Carey, 2009). In many cases these terms can be used interchangeably but for the most part refer to a similar mental entity. For ease of reference diSessa (2002) uses the term, 'concept' to refer to these mental entities and representations. He describes the lack of well-developed technical terms as one of the difficulties of the current views on conceptual change theory. He further argues that the term 'concept' is too vague and has become a colloquial 'catch-all' term. In its broad sense it has become a blanket term used to group all mental entities in the same category. diSessa and Sherin (1998) examined the literature of conceptual change and argue that even the best and most widely recognised researchers use inexplicit definitions that could implicate ill-defined meanings.

This raises the question on what the definition of a concept could be and how one can differentiate a concept from other mental entities. If authors in the conceptual

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change field are to move away from superficial explanations of conceptual change, there should be a list of types of concepts and guidelines on what sets one mental entity apart from others. Towards achieving at least a small part of this goal, I would argue that one first has to determine what types of mental entities are described in the literature and, secondly, collate these descriptions in an integrated discourse.

Seeing that ‘concept’ has become a colloquial term and is used to refer to all mental entities and representations (Margolis & Laurence 2014; Kok 2017), it is important to describe mental entities using terminologies that are not colloquial, but that are descriptive of the characteristics and structure of mental entities and representations. In the literature that I have studied so far there is one common characteristic of all conceptual change or cognitive development theorists, namely that they propose some *hierarchy and network* in their propositions. After having synthesised relevant studies, I have consolidated the views of various scholars and constructed a hierarchy of mental entities (Figure 2.3) in which I present a heuristic for a discussion of *proto-conceptual primitives* and similar ‘level-attributed’ mind tools, moving to *subnetworks*, *concepts* and then, *theories.*

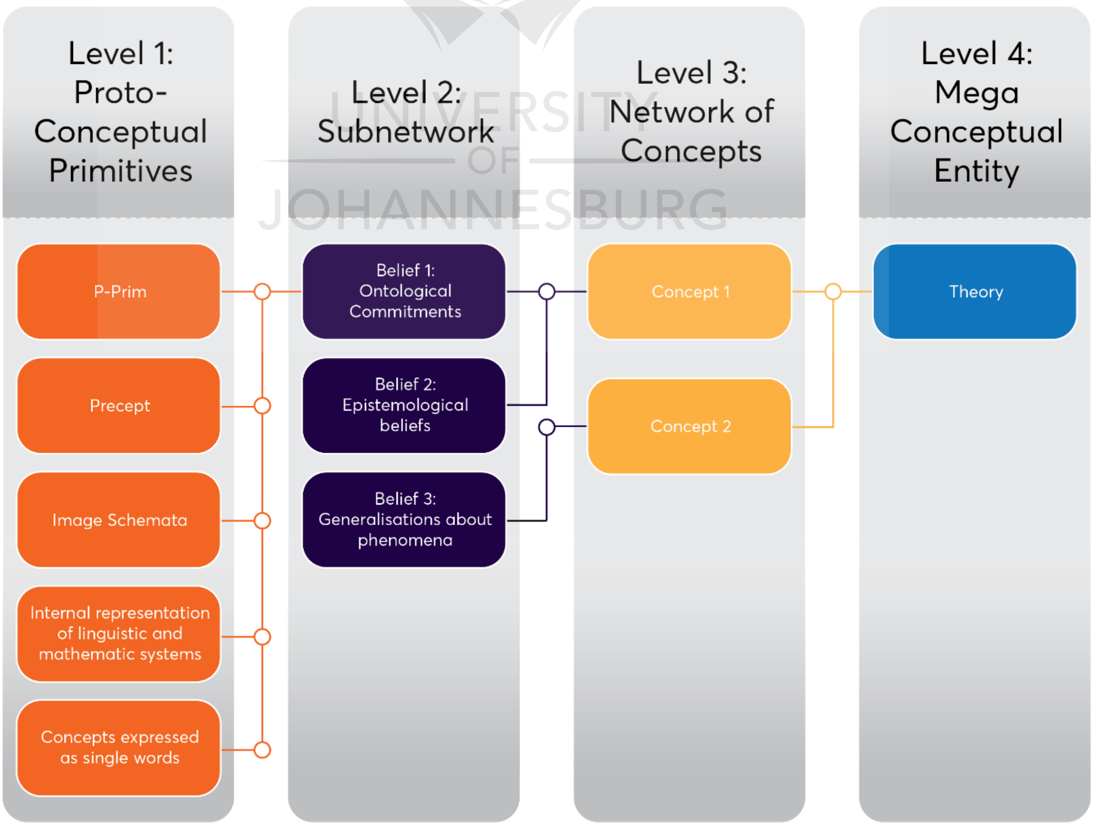

Figure 2.3: Hierarchy of mental entities

This hierarchy of mental entities was created, based on the work of Wiser and Smith (2016) about the relationship between the various mental entities as described by various scholars in the field of developmental psychology, such as Baillargeon (2004), Chi (1992), diSessa (2002), and Gelman (2003). To develop this hierarchy, I considered three assumptions of conceptual change that frame Wiser and Smith's (2016) model of deep conceptual change in science learning. They propose that these assumptions explain why few children achieve deep conceptual change in traditionally taught classes. The assumptions also explain why novel curricula support deep conceptual change and why learning from these curricula should not be hurried. I relay these assumptions whilst also explaining the interactions between the various mental entities in the hierarchy in Figure 2.3.

Wiser and Smith (2016) argue that conceptual change should be understood in the context of evolving complex knowledge systems. They propose, in a similar way to other authors such as Strike and Posner (1992), diSessa (2002), Brown and Hammer (2008), Vosniadou (2013), and Carey (2009), that all concepts form part of a bigger knowledge network, with connections to various kinds of the 'elements'. These elements (as seen in level 1 of the hierarchy in Figure 2.3) include *p-prims*, *precepts* and *image schemata*, *internal representations* of linguistic and mathematical systems, and concepts expressed as single words. These elements express the relationship between words and symbols; propositions that express relationships between concepts; and models that integrate proto-conceptual primitives and the propositions to provide explanations of phenomena. A child may find the statements intelligible or unintelligible; the propositions could be deemed true, false or worthy of consideration; and the models could prove useful to the individual or it could not. It is these elements that determine the *beliefs* (as seen in level 2 of the hierarchy) that an individual holds. These beliefs could be ontological commitments, epistemological beliefs or generalisations about phenomena. The knowledge systems of children include all these previously mentioned elements but are conceptually 'light weight' and comprise concepts (level 3 of the hierarchy) that are different to the knowledge systems of scientists. *Deep conceptual change, mirroring that of the major changes in historic scientific theories, is needed for children to overcome the incommensurability in their own knowledge systems*.

The second assumption on which Wiser and Smith (2016) base their argument is that concepts are both embedded in beliefs and constituted by beliefs. The way in which they phrase this assumption may seem paradoxical but can be resolved by distinguishing between what they term the 'unitary mental symbol' of the concept and the semantic (linguistically coded) meaning of the concept, hence the reason that I have placed this type of concept as a 'single word concept' in level 1. The notion of a 'unitary mental symbol' refers to the word or the placeholder structure as an empty shell that participates in the construction of the belief (see also Carey 2009). The interrelation between the belief with other elements in the knowledge network *constitute the concept* (as seen in level 3) as a structure filled with meaningful content that can be used to explain natural phenomena. The symbol is seen as a "node in the knowledge network, which subtends a subnetwork of relations with other elements in the network." (Wiser and Smith 2016:31)

According to Wiser and Smith (2016) *time scale* plays a role in conceptual change insofar as the degree of incommensurability between conceptual systems (see Section 2.3.2) depend on time scale. They posit that *small changes that are carefully sequenced and directed over a long period of time* could amount to large changes in the structure of a conceptual system without destabilising the system and causing confusion and disbelief.[1] Achieving deep conceptual change is difficult because adding new placeholders and elaborating on existing placeholders is a complex and lengthy process and also requires the reconfiguration of existing subnetworks that would allow the integration of existing elements into the structures provided by the linguistic placeholders. The interconnectedness of the concepts on level 3 give rise to theories (level 4 of the hierarchy) that the individual holds and uses to interact with the natural world whether it is explanatory or exploratory interactions.

Before further explaining the structure of this hierarchy I discuss the work of some of the scholars on whose theories I have built my understanding of conceptual development and conceptual change. In the sections that follow I discuss the work of Lev Vygotsky, Jean Susan Piaget, Carey and Andrea diSessa as proponents of specific views. Thereafter, I explore the learning mechanisms that allow for the change in the network of knowledge systems of an individual, before returning to the hierarchy

[1] This has implications for the pacing in pedagogy – an aspect of the South African mathematics curriculum in the early grades which is of great concern for its fast pace and it disparate topics

of mental entities, in Figure 2.3, where I will argue for the use of this hierarchy as analytical lens of this study.

2.3.2 Conceptual acquisition and development as described by various scholars

Lev Vygotsky

One of the earliest psychology scholars of the 20th century, Lev Vygotsky, argued that conceptual development and the ability to reason is mediated through signs and symbols that are embedded within cultural practice and language (Vygotsky 1978; Reiber 1997; Kozulin 1990). He emphasised the importance of word meaning as the unit of analysis for studying the development of concepts (Smagorinsky et al. 2003), 'precursing' what Carey (2009) would later refer to as 'placeholders' in the case of the word as a beginning towards understanding and forming concepts. Language is a cultural tool and simultaneously also a main, communicative sign system that children learn through their interaction with their immediate community; this means the meaning they attribute to words are *socially embedded*. He argues that ''the speech of those who surround the child predetermines the paths that the development of the child's generalisations will take'' (Vygotsky 1978:143). The meaning attributed to words not only represent the literal, denotative meaning, but also represent the values of the immediate community. The words that a child learns, in essence, become *cognitive placeholders* for the mental representations that the child formulates while interacting with his environment. These placeholders are represented in the hierarchy of mental entities (Figure 2.3 on level 1 - 'concepts expressed as single words').

Vygotsky described two types of concepts, spontaneous concepts and scientific concepts, proposing that spontaneous concepts develop through cultural interaction and exposure to natural phenomena that occur within the individual's context. Due to the context specificity of spontaneous concepts, individuals struggle to apply them when encountering and explaining novel situations. Scientific concepts, on the other hand, are those learnt during formal instruction and are more readily applied when explaining novel phenomena because these concepts are based on general principles as supposed to being context dependent.

Vygotsky argued that humans travel, cognitively, on a journey towards unifying concepts on a "twisting path" (Vygotsky 1986:156) that starts at spontaneous concepts and moves through life, learning along the journey (also through instruction) not reaching the final destination (ever). Along this journey of learning and development

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he identified two approximate concept types that show conceptual progress, but not yet achieving full ‘scientific’ conceptual status. He referred to these initial stages of development of concepts as ‘complexes’ and ‘pseudoconcepts’. According to his theorising, a ‘complex’ is characterised by some representations that are unified with some related representations of a concept but not all representations are unified in a shared general principle. Vygotsky (1986) argues:

> If empirically present, any connection is sufficient to lead to the inclusion of an element in a given complex. The concept is based on connections of a single, logically equivalent type. In contrast, the complex is based on heterogeneous empirical connections that frequently have nothing in common with one another (Vygotsky 1986:137).

Pseudoconcepts are characterised by representations that appear entirely unified but contain internal inconsistencies. Vygotsky (1986:144) refers to a pseudoconcept as a “shadow of the concept” because it appears to be the concept but connects the elements of the concept on simple association. These approximate concepts might be better understood using an example. If a child learns to classify a fish and proceeds to classify all aquatic animals as fish the approximate concept would be a complex. However, if the child learns that all fish have fins and proceed to classify all aquatic animals with fins (including mammals like whales, dolphins and sea lions) as fish, the approximate concept is classified as a pseudoconcept. The full scientific concept would allow the child to differentiate between the notion of fish and aquatic mammals.

Vygotsky’s brief oeuvre, captured in the volumes in the Complete Works of Lev Vygotsky (Vygotsky 1997) includes most aspects of child development, but his contribution to developmental psychology and human activity is especially in how he integrated knowledge of signs and tools as semiotic mediators in the forming of concepts (Davidoff 2001; Chaiklin & Lave 1996; Alvarez 1994).

Jean Piaget

Piaget, a zoologist who became a developmental psychologist and epistemologist, is regarded as one of the pioneers of constructivism as a theory of knowledge. In his theory of cognitive development, he identified two challenges. Firstly, that of explaining the full repertoire of human conceptions, how one acquires specific concepts, discovering which conceptual primitives are innate, and which processes are involved in the transformation, through learning, of concepts to reach an adult state of knowing. In other words, he attempted to answer the question of how new conceptual content is acquired. The second challenge is the characterisation of domain general cognitive resources that enable the construction of concepts as well as explaining the developmental changes that occur in the cognitive architecture. These two challenges influenced each other in that the development of domain general cognitive resources in our biology would constrain the acquisition of new concepts and therefore inhibit learning for domain specific knowledge. For Piaget it was clear that the biological development of the nervous system had to precede cognitive development and this is where his stage theory came into play. As children matured they would increasingly be able to expand their conceptual repertoire. Even though the specifics of his stage theory are now called into question, the basic premise of stage theory remains relevant as most contemporary developmental psychologists agree that changes in domain general cognitive resources are vital for conceptual change.

To understand the development of knowledge, for Piaget, it was imperative to describe the essence of knowledge which he termed an ‘operation’. An operation as a mental entity could be useful actions such as classification, ordering things into a series, and counting. He defined an operation as “a set of actions modifying the object, and enabling the knower to get at the structures of transformation” (Piaget 1964:177). He further explained that operations are never isolated and form an interconnected network of actions that form a total structure. These operations formed the basis of knowledge that would aid in understanding the development of knowledge by elucidating the “formation, elaboration, organisation, and functioning of these structures” (Piaget 1964:178). He termed the larger conceptual structures, such as realising object permanence, as ‘’schema. Learning as the process by which existing knowledge is transformed into new understanding is driven by the processes of equilibration of assimilation and accommodation.

During learning processes, a person’s current ideas or concepts will interact with the new information that he is being taught or engages with through investigation. It is not uncommon for the person to reach an understanding that is fraught with errors and misconceptions that are difficult to replace with more accurate concepts due to the robust nature of, what Posner et al. (1982), refers to as ‘alternative frameworks’. Piaget (1964) believed, as many current scholars still do, that learning needs to be an active enterprise in which novel experiences and information interact with the current ideas. It means, thus, that a person's schema will fit with new learning and that new 'content' will be assimilated into the conceptual framework, or will be so contradictory that the schema either, rejects the new information or the structure of the schema should be reorganised in order for the new information to be accommodated. Piaget states that in the 'act of knowing', the learner active. This means that faced with an 'external disturbance', he will respond to compensate for the disturbance and will 'equilibrate'. The conceptual framework of the individual is therefore reorganised in such a way as to move away from 'disequilibrium' towards a more stable state of equilibrium. Learning of subsequent concepts that require a stable 'ancestral conceptual framework' will not occur if equilibrium has not been achieved in the 'ancestral conceptual framework' first.

The research field of conceptual change has progressed significantly since the collective work of Vygotsky was published in 1987 and the contributions of Piaget and has spawned two competing theoretical perspectives on knowledge structure coherence (Ozdemir & Clark 2007). Recently two schools of thought have emerged about the nature of knowledge construction. Some scholars propose 'knowledge-as-elements', and others refer to knowledge construction as the revision of theories, the so-called 'knowledge-as-theory' proponents. In my reading of the literature I have understood there to be a consolidated view of knowledge construction that includes both these views and have incorporated this consolidated view in the hierarchy of mental entities as depicted in Figure 2.3. In the following section I will compare these two seemingly opposing views as an overview and subsequently describe the two views first, by referring to the work of Susan Carey as a proponent of the knowledge-as-theory perspective and lastly, referring to the work of Andrea diSessa as a proponent of the 'knowledge-as-pieces' perspective.

A brief introduction to and overview of knowledge-as-theory and knowledge-as-elements

The proponents of the knowledge-as-theory perspective argue that a child's knowledge is most accurately represented as a coherent framework of theory-like structures (Carey 2009; Chi 2005; Ioannides & Vosniadou 2002; Wellman & Gelman 1992; Gopnik & Meltzoff 1997; Nersessian 2008). This view is also known as the 'theory' theory of conceptual change. The proponents of the knowledge-as-elements advocate that a child's knowledge is an ecology of virtually independent elements (Clark 2006; diSessa, Gillespie, & Esterly 2004; Harrison, Grayson & Treagust 1999; Linn, Eylon, & Davis 2004). These theorists do not necessarily agree with Fodor's (1975) view of modularity, but they also do not support the theory theory of knowledge-making,

Ozdemir and Clark (2007:352) attempted to clarify the foundations of each perspective and have noted that knowledge-as-theory builds on aspects of Piagetian learning theory and is also strongly influenced by the study of the philosophy and history of science. They explained the essence of knowledge-as-theory as follows:

> To explain a conceptual shift, proponents of knowledge-as-theory perspectives often present analogies between Piaget's concepts of assimilation and accommodation and Kuhn's (1962) concepts of 'normal science' and 'scientific revolution' (e.g., Carey 1985, 1999; Wiser & Carey 1983). While some of these researchers have explained conceptual change in terms of framework theories and mental models (e.g., Vosniadou 1994; Vosniadou & Brewer 1992), others have focused on higher level ontological shifts (Chi 1992).

The opposing perspective proposes that children's understanding can be characterised as collections of various, virtually independent, elements that function as an *ecology*. The interactions and relationships between these elements are seen as the building blocks for conceptual comprehension. Ozdemir and Clark (2007:353) summarises the views of the most prolific authors in the Knowledge-as-elements perspective as follows:

> Anderson (1993) and Thagard (1992) provide relatively mechanical/mathematical examples of this perspective. Clark (2006), diSessa, Gillespie, and Esterly (2004), Hunt and Minstrell (1994), and Linn, Eylon, and Davis (2004) maintain more organic perspectives that focus on collections of elements including, but not limited to, phenomenological primitives, facts, facets, narratives, concepts, and mental models at various stages of development and sophistication. diSessa focuses more on the nature of the elements, Clark focuses on longitudinal processes of change, Minstrell focuses on the facets students use in the classroom, and Linn focuses on the process

through which students reorganize, revise, and connect these elements. Learning occurs through a process of restructuring and reorganizing these ideas.

In their comparison of the two perspectives Ozdemir and Clark (2007) note that there is agreements on some aspects of conceptual development. These include 1) children acquire knowledge from their daily experiences; 2) children's naïve knowledge influences their formal learning; and 3) naïve knowledge is *highly resistant* to change, thus implying that conceptual change is a time-consuming process. The disagreements, however, are rife and would best be compared as follows:

Table 2.1: Knowledge-as-theory and knowledge-as-elements (adapted from Ozdemir and Clark (2007))

Knowledge-as-theory	Knowledge-as-elements
Naïve knowledge is highly organized in theory, schema, or frame forms.	Naïve knowledge is a collection of quasi-independent knowledge elements.
Naïve knowledge in a coherent form has explanatory power to consistently interpret the situations across broad domains.	Consistent application over time for individual contexts, and systematicities will be present, but high contextual sensitivity.
More focus on revolutionary replacement of naïve knowledge in a manner similar to Kuhn's perspectives on paradigms in science. Significant coherence between ideas at any given point in time.	More focus on conceptual change involving evolutionary revision, refinement, and reorganization. Multiple conflicting ideas may coexist simultaneously at any given point in time.
Explanations involve the creation of mental models constrained through the overarching framework theories or ontological categories.	Explanations involve the p-prims and other elements within the learner's conceptual ecology that are most strongly cued by the context.

I now continue by exploring the nuances of the two perspectives by focussing on the views of the two prominent authors as mentioned earlier.

Susan Carey and other proponents of knowledge-as-theory

Susan Carey is a professor of psychology and a contemporary theorist of childhood cognitive development and is known for the impact she has made in the field of childhood cognition. Her work touches on the main trends in this field and highlights contemporary ideas of conceptual change theory. In 1985 she published *Conceptual Change in Childhood* in which she analyses young children's biological knowledge. Her latest book *The Origin of Concepts* (2009) is an extensive study on how concepts develop as children mature.

Carey (2009) refers to initial concepts as 'intuitive theories'. She defines these theories "as theories that ground the deepest ontological commitments and the most general explanatory principles in terms of which we understand our world." (Carey 2009:26). Children attempt to make sense of the world around them from an early age by unconsciously employing basic informal empirical activities. It is through the repetition of these activities that they form these early intuitive theories. Gopnik (2011) would argue that this process is inductive and that Bayesian theory can explain some of it.

Carey writes that concepts are "units of mental representation, roughly the grain of single lexical items, such as object, matter, weight" (Carey 1992:89). These mental representations are part of many computational processes, such as inferences, predictions and explanations of phenomena. A child can form an initial concept that could be consistent with the generally accepted formal empirically-based explanation of that concept or could form a concept that is far removed from the general view of that specific concept[2]. In other words, young children form mental representations according to what they encounter and observe. Carey (2009) and Gopnik (2011) describe the acquisition of the initial concepts in terms of the theory-theory of conceptual development. Intuitive theories of natural phenomena are built by combining a myriad concepts and unconsciously postulating a *relationship* between these concepts until they make logical sense (at least to the individual child). Because

[2] This would be similar to what Lev Vygotsky referred to as 'spontaneous concepts' and 'scientific concepts'.

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of this almost haphazard combination of concepts, a child's intuitive theory of a natural phenomenon might not be entirely consistent with the generally accepted (adult) explanation of said phenomenon. Added to that, a child forms concepts that are not mediated by language at first and the concepts/representations adapt as language and other forms of symbolic representation increase (Henning & Ragpot 2015).

Carey (2009) as well as other authors (Gopnik & Meltzoff 1997) that are proponents of the knowledge-as-theory perspective argue that children's conceptual structures are theories that are comparable to those of scientists. They further state that theory formation and change forms the basis of children's conceptual development and that these theories guide the child's semantic development – awarding meaning to words. They propose that both children and scientists seek truths regarding the natural world by forming theories. Gopnik and Meltzoff (1997) shows similarities between scientists and children as theory formation in both instances are based on observation of the natural world and making sense of phenomena by conceptualising possible causes. These observations and conceptualisations are central to the cognitive development of the child as it is central to the formation of scientific theories (Carey 2009; Carey & Spelke 1996; Gopnik & Meltzoff 1997). Henning (2012) explains that the similarities between the theories children form and scientific theories are that conceptualisation of reality includes the identification of a concept's most important characteristics, the representation of explicit and explanatory knowledge, as well as the support of explanatory assumptions.

Just as scientific theories can change, based on new empirical evidence, so too can children change their theory, based on new empirical knowledge gained about a phenomenon, and which can aid in making more accurate predictions and explain the phenomenon. A scientific theory needs to be falsifiable for it to be regarded as a theory (Popper 1957). Therefore, when counter evidence is presented, contrary to the premise of the held theory, the theory needs to be adapted to include an explanation of how the counter evidence can fit the theory. If this is not possible, the theory is abandoned, and a new theory has to be developed taking all the empirical data into consideration.

A currently held theory need not be true for anyone except the child herself. It merely has to make sense within, what Carey (2009) refers to as a child's *conceptual systems*. If new evidence is presented that does not fit the conceptual system, conceptual change has to occur in order to assimilate the new evidence. There has to be, in Piagetian parlance, some ’disequilibrium’, when ‘assimilated’ knowledge cannot be ‘accommodated’ (Piaget 1964). Gopnik and Meltzoff (1997:41) argue that when children employ the skills of prediction, interpretation and explanation, it is an indicator of the existence of theoretical structure and, thus, the ability to recognise the need for ‘change’ (of a theory). In this way, children build various theories, using information they have available and which they, intuitively, connect to what they already know. After intuitive theories have taken shape, and when a child enters formal schooling, the challenge arises to adapt the intuitive theories to fit the theories held by teachers and the curriculum.

If teachers do not know the ‘theoretical state of mind’ of children, they may introduce standard theories (such as additive relations in mathematics, of a vitalist view of biology, or observational astronomy), without cognisance of what children know and believe. This is the eternal challenge for education from the viewpoint of a constructivist epistemology.

It is, then, during the child’s schooling that most of the initial concepts (whether ‘naïve’, or ‘intuitive, as described by Carey (2009) and diSessa (2002)) have to be explored by teachers. I would argue that most teachers assume certain knowledge (or a ‘blank slate’) and teach the curriculum somewhat ‘blindly’. However, if a teacher were able to ascertain what children know and believe, and what their theorising about, for example, a phenomenon about ‘living and non-living’ objects is, she may have a better idea about the conceptual systems from which children draw. Carey has suggested in her oeuvre, which it is not only individual concepts that change, but that a shift also takes place in what she refers to as ‘conceptual systems’ (Carey 2009:364). She argues that when various components of understanding conjoin and form understanding, that this process of “bootstrapping” seems as if a child has ‘pulled herself up by her bootstraps’, but that it has more to do with the gradual linking of components of understanding that lead to conceptual change and thus of a change in the conceptual system. According to Carey (2009:414), the Quinian term, ‘bootstrapping’ refers to a process through which new conceptual ‘primitives’ are introduced into thought. Quinian bootstrapping stems from the metaphor developed by the philosopher Quine (1966) who used metaphors, such as that of “Neurath’s boat”, to explain the idea of learning processes. The metaphor of bootstrapping is an analogy that means “to pull oneself up by one’s own bootstraps” which is physically impossible (Carey 2009:20). When applied to conceptual change, to pull yourself up

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by your bootstraps will mean to create new “representational resources that are not entirely grounded in forerunner representations” (Carey 2009:20).

The metaphor of Quinian bootstrapping is a functional lens to view the ability of humans to create theoretical knowledge that surpasses innate knowledge, often referred to as ‘core cognition’. This is achieved by using external symbols, such as words, as placeholders for concepts that do not yet resemble the normative concept. Meaning is gradually assigned to these symbols as the explanatory power and problem-solving abilities of concepts lead to failed predictions and contradictions.

Carey (2009) refers to this change as a move from the ‘old’ conceptual system as conceptual system 1 (CS1) to the ‘new’ conceptual system as conceptual system 2 (CS2). I would then argue that teachers must have some insight in what children’s CS1 is in order to mediate/ teach/ instruct with the aim of getting children to build CS2. In science teaching the pedagogical mechanisms for this are not prescriptive. Through systematic instruction children can ‘reform’ or adapt their initial understanding to ‘fit’ the scientific accurate concept.

The mechanisms used in this ‘re-formation’ or change process are grouped in a broader theory known as ‘conceptual change’ theory (see Vosniadou 1994; Carey 2009; diSessa 2002; Barner & Baron 2016). Conceptual change is an extremely difficult process in most cases as the semantics of the ‘new’ concept is mostly incommensurable with that of the ‘old’ concept. When enough learning has taken place, and when substantial individual concepts have changed, a ‘new’ conceptual system comes into being. The process of moving cognitively from CS1 to CS2 requires conceptual change to occur with single concepts and with groups of concepts that are interrelated to form understanding. Coupled with conceptual change is the use of symbolic representation, such as is captured in language. In Figure 2.4 the diagram shows the relationship between certain concepts and the conceptual system they form part of.

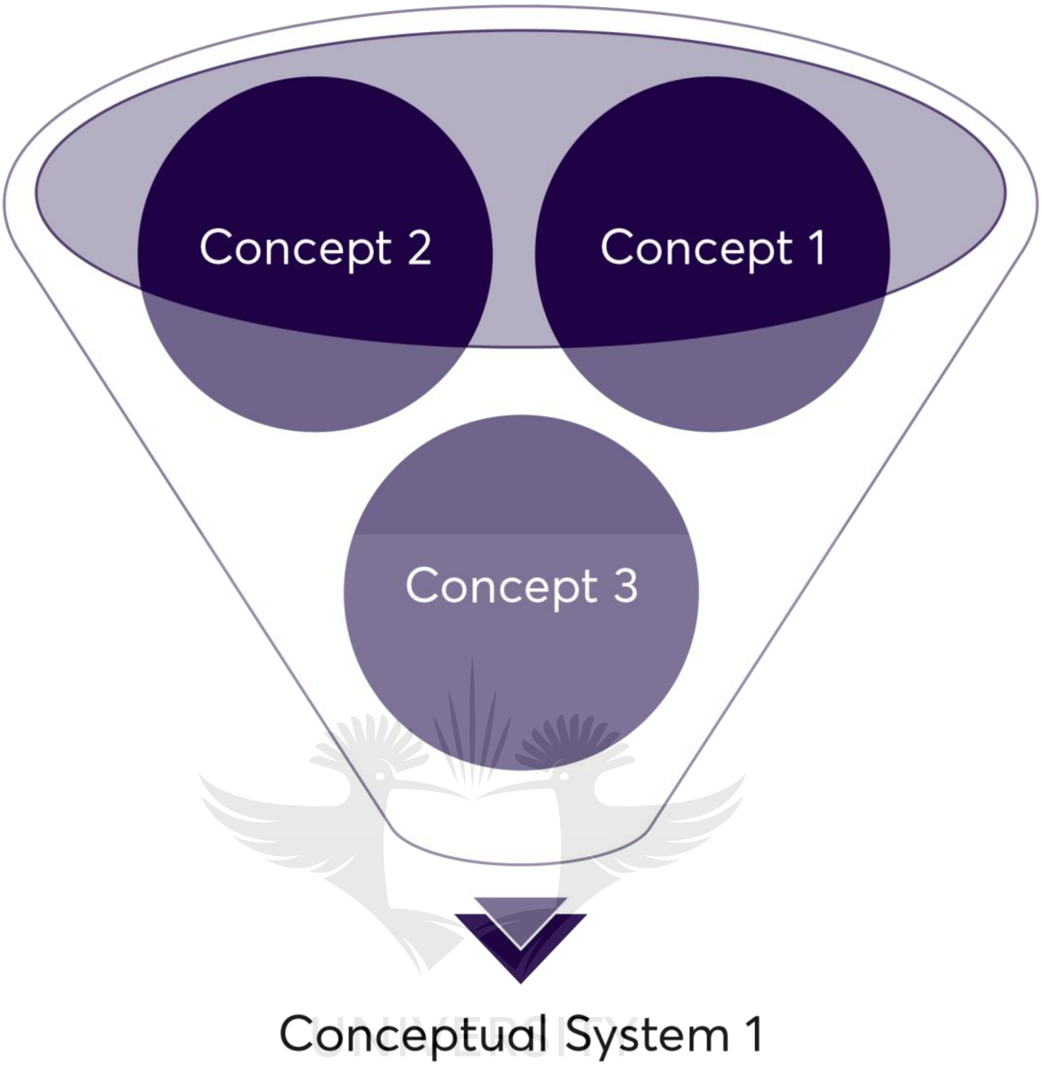

Figure 2.4: The combination of and relationship between various concepts forms the conceptual system

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Carey refers to the change from CS1 to CS2 as a form of bootstrapping. By this she means that when a number of conceptual changes have taken place in, for example a child’s understanding of the concept ‘growth’, there may be a substantial conceptual shift in the conceptual system of a child’s theory of vitalist biology. (See Figure 2.5)

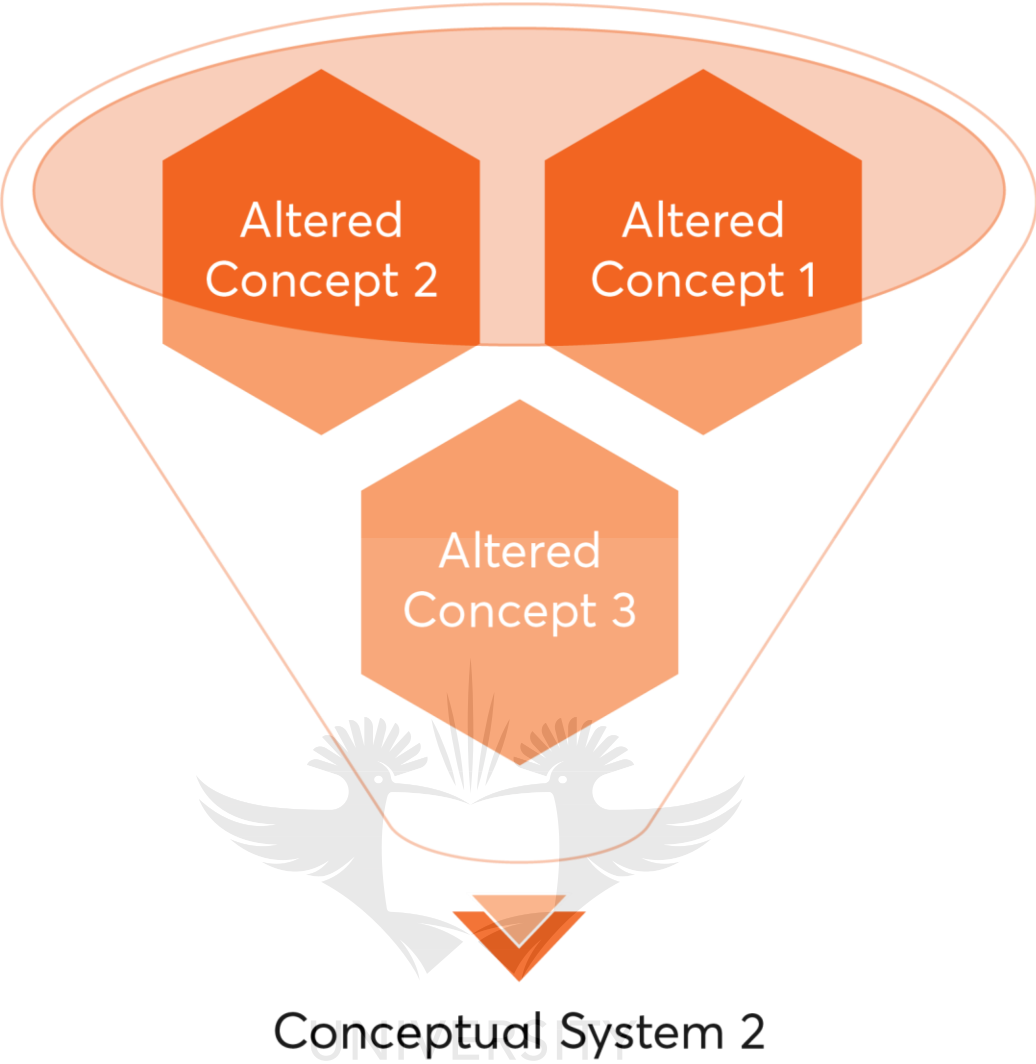

Figure 2.5: The tipping point in conceptual change

As concepts get altered, or new concepts are added into a conceptual system, gradual change occurs until a tipping point is reached that completely alters the entire conceptual system. This view of learning, where initial concepts are altered after new information has come to light, suggests that change requires complicated interactions between the initial knowledge and the new information (Chinn & Brewer 1993). Ohlsson (2011) refers to this type of learning, where the child must replace or reject his initial concept, as 'non-monotonic': This results in the growth as well as the recession of the child's knowledge base. Monotonic learning occurs when a child adds new knowledge to his memory where there is little to no change to the existing knowledge base (Ramsburg & Ohlsson 2016).

Somewhere along the road to clear understanding of science concepts, children build and expand on their intuitive theories, going through the processes that Carey (2009) and the other proponents of knowledge-as-theory describe. It is at this point where various conceptual systems integrate and learning is forcefully expanded and a child can use symbolic means, such as language, to explain her understanding, that mental representations are articulated. The various learning mechanisms that facilitate the bootstrapping process will be further discussed in Section 2.3.3.

Andrea diSessa as proponent of knowledge-as-elements

This section summarises the arguments and postulates of Andrea diSessa and other authors who are proponents of the 'theory-as-elements' perspective, regarding the elements of conceptual change theory. According to diSessa (2002) a major critique of the state of conceptual change theory is the lack of theoretical accountability regarding the nature of the mental entities involved. He further argues that the complexity and diversity of conceptual change phenomena is vastly underestimated. In his opinion, research during the late 20th century and early 21st century into conceptual change has taken a vastly oversimplified view of the process. It was mostly seen as the transformation of a single mental entity and this transformation was often described as a concept that starts off as a superficial mental representation of a natural phenomenon and then evolves into a clearer more nuanced representation of the phenomenon that resembles the common understanding of a community, which diSessa (2014) refers to as the *normative concept.* As an example, he refers to how children have an innate understanding of objects that are alive by categorising these objects, invoking characteristics such as movement and breathing as the determining factors of their classification. (A more detailed discussion on the naïve theory of vitalist biology follows in Section 2.4). As their concepts of movement and, more particularly the mechanisms of movement, become more nuanced, they distinguish between autonomous movement and that of movement caused by external factors, for instance, a leaf blowing in the wind versus actively contracting muscles that allow animals to move. This new understanding of movement allows children to reclassify objects that they have previously described as living to the new category of non-living. The transformation is thus from a simplified superficial understanding to a more nuanced and deeper understanding.

Figure 2.6 shows how many authors draw a simplistic assumption when describing conceptual change.

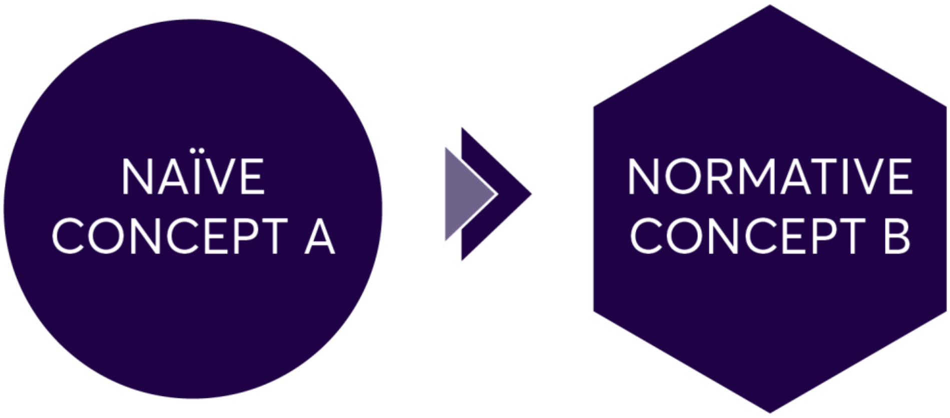

Figure 2.6: Simplistic assumption of the change of a concept that occurs when learning

The representation of concept A that leads to concept B more or less implies that there is only one naïve concept for every expert concept. It fails to acknowledge that expert concepts could be formed due to a combination of several naïve concepts. diSessa (2002) proposes a 'complex knowledge system' view of conceptual change, in which multiple naïve concepts gradually change and these changes lead towards conceptually competent expert conceptual ecologies. He echoes the sentiments of Brewer (1989):

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> In the long run, a proper understanding of the human mind will require that we recognise a large number of very different forms of knowledge and associated psychological processes (Brewer in Vosniadou & Ortony 1989:537).

He argues that many naïve scientific ideas are inarticulate and not easily expressed in words. This stands in stark contrast with professional science, where complex, careful and symbolically augmented expression is almost always evident. In professional science the externalisation of ideas allows for reflective scrutiny and careful reformulation of hypotheses. Teachers cannot see naïve theories of children directly and therefore struggle to assist young children in reflection that will allow them to reformulate their naïve theories.

diSessa (2002) argues that scientific concepts are best considered as complex systems and proposes that conceptual change be viewed as 'conceptual ecologies' that involve many diverse kinds of knowledge that are organised and reorganised into complex systems. To comprehend the nuances of these ecologies, we first need to describe the 'monomers' of these systems. In his view, these ecologies consist of two types of mental entities: 'phenomenological primitives' (p-prims) and 'coordination classes'. Simply put - p-prims can be described as elements that are generally taken as a fact of life and requires no further explanation (diSessa 1988). P-prims are small and numerous intuitive elements that are often context specific in their activation. When encountering a specific phenomenon, one does not employ all p-prims to aid in comprehending the causes of said phenomenon. It is only the p-prims that are *relevant* to the phenomenon that are deployed to attempt to understand the causes of this phenomenon - hence the context specific nature of p-prims. 'Coordination classes' are large systems that entail a high degree of coordination *across* diverse contexts. The comprehensions of a novel phenomenon can be achieved by employing the coordination classes that have previously been constructed. From this we start seeing polarisation in the hierarchy of conceptual ecologies, with p-prims as the 'monomers' and coordination classes as the 'polymers'. diSessa (2014) claims that p-prims constitute the bulk of intuitive physics. Throughout diSessa's work he attempts to describe the properties of p-prims. He determines these properties using clinical interviews.

diSessa (1993, 1996) identifies the characteristics of p-prims in interviews, in which the subjects have to predict and explain physics phenomena. One aspect of his argument is that no other authors account for the changes in 'many and little' elements, like p-prims. The 'large,' intrinsically difficult to change entities, like concepts, theories and ontologies provide no explanation for commonplace cognitive phenomena. Learners' descriptions of physics phenomena emerge on the basis of intuitive resources and their properties. When they describe phenomena, the descriptions are at first semi-stable configurations of known entities with known properties, even though these are constructed on the spot. Such descriptions show a cognitive entity that is not yet a theory, but does show how p-prims penetrate into the details of process data.

He argues that clinical interviews are one of the best empirical tools as it allows repeated episodes, involving a particular mental entity, and allows triangulation on the properties of the entity. Other advantages of clinical interviews include the allowance of a nuanced setting of the context that allows for the investigation of contextuality; it elicits the participants' levels of commitment as their certainty or ambivalence is evident in their responses; it exposes paths of reasoning that lead to answers whilst extricating answers from the ideas that spawn the answers. Furthermore, clinical interviews allow for the opportunity to investigate small changes in learning that contribute to conceptual change. This final advantage addresses one of diSessa's biggest criticisms of conceptual change research: In his view, conceptual change research is mostly concerned with macro changes, because sampling of the change in mental entities mostly occur at the initial phase, prior to instruction or intervention, and again following instruction or intervention. This form of 'snapshot' conceptual change studies' lenses are fuzzy and can be improved by decreasing the *grain size* of these studies (diSessa 2002). Clinical interviews aid in tracking the micro changes of mental entities and therefore allows for a more nuanced description of the mental entities themselves. It is these clinical interviews that allowed diSessa to describe the properties of p-prims. In the following sub-section I will list the properties of p-prims as diSessa describes them:

Small and monolithic

diSessa refers to p-prims as 'being small' and describes them as 'being simple' knowledge elements. He compares the size of p-prims to that of atoms. It is therefore the smallest functional structure of a mental entity and is invoked as a part of the whole. P-prims are different to scientific concepts, as these concepts can only be accounted for with a systems analyses.

P-prims are numerous

There are possibly thousands of p-prims and the full set of p-prims exhibit some degree of systematicity but the nature of this systematicity is fragile and the bonds between p-prims are loose. When compared to other mental entities like theories they exhibit deductive relationships and little degree of systematicity.

Work by recognition

The simplest model for the activation and use of p-prims is recognition. They are activated only in certain instances and therefore can be recognised only when activated. One can argue that the absence of a p-prim in the discourse of an individual that is usually prominent in a specific situation, is, in itself, meaningful.

Feelings of naturalness; judgements of plausibility

The function accomplished by p-prims is to provide a sense of obviousness and reassures the necessity to events. By example, you are not surprised when an event plays out in the same way that you predicted the outcome of the event. You are not surprised when a pulling force is exhibited on an object and the object proceeds to move in the same direction as the pulling force. The resultant movement correlates with the naturalness of the prediction as it matches the intuitive p-prim related to the circumstance at hand. Similarly, there would be great surprise if the resultant movement was contradictory to the envisaged outcome. This could possibly explain the surprise that children experience when they observe chemical reactions or when they witnesses illusions used in the repertoire of illusionists.

Explanatorily primitive

The causes of the behaviours prescribed by p-prims are unknown. diSessa (2002) claims that there is no 'covering theory' or articulate reasoning that explains the causes of the behaviours of p-prims at this stage.

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Fluid, data driven; lack of conflict resolution

Often, p-prims might be less firm in their activation, even though they are strongly queued by a situation. In these cases, individuals may have an intuition about what might happen but then lose it as their attention shifts. In certain situations, many conflicting p-prims may be called upon but it is unlikely that there will be any means of resolving the conflict.

Problematic connection to language

Describing p-prims linguistically is nearly impossible as p-prims cannot be fathomed as constructs such as words or word senses.

Origins in "minimal abstractions"

It is not rare or difficult to generate new p-prims. Often, they are abstractions of familiar events such as an object that is pulled would have a resultant movement in the same direction as the force pulling on it. These abstractions are easily accomplished and are determined by an extended developmental process.

Development by reorganisation

The learning of scientific concepts does not extinguish or replace p-prims. Instead, the different p-prims find a useful position within the greater system of the concept. An individual p-prim could become an effective special case of a particular scientific principle and could be used in the place of said principal when the opportune circumstances present itself. In this case the p-prim will no longer function as explanatorily primitive. This evolution of a selection of p-prims can be described as "shifting priorities" in a particular useful context.

These properties of p-prims are not to be viewed in isolation but the full combination of these properties are mutually dependant as many properties provides causal fodder for the existence of subsequent properties. An example of such mutual dependency is the properties of small grain size and large amount of p-prims. The mere fact that a p-prim is small allows for the large numbers of p-prims. This is also further aided by the property that p-prims are easily generated.

Now that I have discussed the properties of p-prims it is imperative that we discuss certain examples of p-prims that have been studied. diSessa (2002) discusses a few examples of basic p-prims, p-prims associated to the concepts of balance and equilibrium and mentions one less important p-prim.

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Basic P-Prims:

Ohm's P-prim

Briefly, 'Ohm's p-prim' explains that more effort leads to more results and that more resistance leads to less results (Genter & Stevens 2014). There are three elements involved in many natural interactions: impetus, resistance and result. Naude (2015) shows how young children use this p-prim when predicting what would happen if vinegar is added to a balloon filled with bicarbonate of soda. When asked what would happen when more reagents are used in the demonstration most of predictions came almost instantly as the class 'sang' spontaneously that the balloon will inflate more than during the demonstration where they used less reagents. Even though the resistance that the balloon provided remained the same, it was clear to the children, who noticed the relationship between the increased impetuses leading to an increased result.

Force as a mover

Objects move in the direction that they are pushed in. This p-prim relies on the intuitive notion of resultant forces. The interaction of one object on another results in a change in spatial position of both objects.

Dying away

This p-prim relies on the phenomenon that invisible forces, for instance friction, impedes in the continuous motion of an object. In essence it states that induced motion dies away or simply put that something that starts moving due to an external force will not continue moving indefinitely but will gradually stop.

P-prims for balance and equilibrium:

Dynamic balance

This p-prim shows that the result could be cancelled out when there is conflicting effort. When two forces of equal magnitude interact in opposite directions there is no resultant movement and the effects have been cancelled out.

Overcoming

When one of the conflicting parties increases the effort or the effort of said party wanes it yields a result that is different from the instant when the effort was in equilibrium. As an example, the team that is victorious in a tug of war wins the competition if the effort they employ is greater than that of the opposing team.

Return to equilibrium

When a system is “out of balance” it will return to a state of balance and reach equilibrium. This is most notable when a balance scale is disturbed by placing weight on the one side of the scale. When the weight is removed the scale returns to a balanced state.

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Generalized ‘springiness’

This p-prim shows that the magnitude of disturbance influences the displacement from equilibrium. The greater the magnitude of the disturbance the more perturbed the system would be.

Less important p-prim:

Contact conveys motion

Small objects that are in contact with larger objects will move with the larger object. This p-prim does not inherently assume the mass of the object but rather isolates the size of objects. It is for this reason that you intuitively assume that a bag of apples placed on the back seat of your car would travel with the car.

Another term that diSessa (2002) uses in his attempt to produce accountable theoretical terminology is that of *coordination classes*. Coordination classes have properties that are for the most part polar opposites of p-prims. The contrast is due to these classes being large, complex systems, as opposed to the atomic nature of p-prims. The coordination classes are made up of numerous p-prims - and p-prims are seen as the fragments of coordination classes. Coordination classes therefore constitute a model or mental representation of a certain type of scientific concept. Due to the amalgamation of different p-prims in varying instances, coordination classes have a range of parameters that imply that the construction of a coordination class may be different in one case compared to another. diSessa (2002) argues that coordination classes do not exist in naïve thinking but rather that p-prims are the evident mental entity during naïve thinking.

The function of p-prims is to provide a sense of ‘naturalness’ in familiar situations, surprise and possible learning-inducing attention in situations not understood, and expectations that can be instrumental. Coordination classes have a very different functionality. Coordination classes provide a means to *collect a certain class of information from the world.* The fundamental assumption of coordination classes is that information is not transparently available in everyday reality and that we therefore have to learn how to access the different kinds of information when it is uncovered. In varying circumstances, we employ different means to determine the same kind of information, because the varying circumstances in themselves *recall different p-prims*.

I compare this construction of coordination classes to that of protein synthesis. There is a limited number of amino acids available to serve as the building blocks for protein synthesis. When amino acids are sequentially bonded they form a chain that eventually results in a protein with certain characteristics. When the sequence of amino acids change it results in a protein with different characteristics than the initial protein. This change in structure has a definite influence on the morphology of the protein and consequently an influence on the function of said protein. This leads to the diversity of all known proteins which by extension leads to the diversity of life. This diversity is achieved due to variance in the sequence of only 22 amino acids. When you compare the construction of coordination classes as proposed by diSessa to this example of protein synthesis it becomes evident why the mental entities of one individual could be vastly different to those of another. If the number of available 'monomers' (amino acids in the case of protein synthesis and p-prims in the case of the construction of a coordination class) increase it leads to greater diversity of the polymer (the protein or the coordination class).

Coordination classes have substantial internal structure and therefore large-scale partitioning of coordination classes can be made. diSessa (2002) distinguishes between the methods by which relevant information is gleaned from the world, which he calls 'readout strategies' and the collection of possible inferences that can be drawn from available information which he calls the 'causal net'.

One example that diSessa (2002) uses to illustrate the functioning of a coordination class stems from Piagetian studies of children's concepts of time (Piaget 1969). "Time interval" is the coordination class he uses as example. The problem posed to children is that of two trains that leave the station at the same time. One train (the blue train) is slower than the other (the red train). The red train stops before the blue train stops. Due to the difference in speed the blue train does not catch up to the red train by the time that it stops. When asked to choose which train "went on for longer" most children answer that the red train went on for longer. When probed about the scenario it is evident that children can extract substantial information, showing that they have adequate 'readout' strategies. Adults, on the other hand, can extract the needed causal information related to the relative stopping of the trains and also know that information pertaining to relevant position has no bearing on the question at hand, indicating that adults have a 'causal net' that contains the appropriate inference on the basis of relevant observations.

This does not imply that children do not have a 'causal net', but rather that children's causal nets are different to that of adults. The inference that they make is that an object that travels for a longer time equates to greater distance travelled. The children aren't aware of the applicable conditions of this inference and that it is only true for objects that move at the same speed.

The development of coordination classes is an extended and complex process. 'Coordination' refers to multiple pieces that must be put in place to achieve an effective coordination class. This process, however, is riddled with challenges like the example explained above. One must use both 'readout' strategies and inferences in the causal net that is sufficient to include all contexts of the needed information if you want to extract the information of interest. diSessa (2002) refers to this state as achieving the appropriate 'span'. When particular 'readout' strategies and inferences are combined. diSessa (2002) refers to it as 'integration', because it appropriately integrates several pieces of knowledge to serve the needs of a particular context. Due to different 'readout' strategies, different inferences and different combinations may be used in differing circumstances, and a properly formed coordination class must be 'aligned'. Alignment is only achieved if the same information is 'read out', regardless of the context and regardless of the 'readout' strategies and inferences that were used. *It is this alignment that teachers strive to achieve when teaching*.

The prominence of a particular p-prim prevents alignment in coordination classes. If the principles applied to explain phenomena in varying contexts result in deviating explanations alignment is not achieved. This therefore could be an indicator that teachers could use to diagnose the learners' comprehension of a phenomenon.

diSessa (2002) claims that p-prims and coordination classes are more specific than dictionary definitions of concepts and theories and postulates that p-prims and coordination classes *are plausible knowledge types* that play distinct roles in conceptual change and account for different conceptual change phenomena. He argues that p-prims account for intuitive predictions and judgements of plausibility and that coordination classes provide a specific model of a type of full-blown concept which entails a lot about the difficult and easy parts of conceptual change. diSessa (2002) argues that, in theory, p-prims are distinctly different from coordination classes but empirically very difficult to identify and requires great scrutiny to determine which of these knowledge types are involved. diSessa (2002) predicts that one would need to

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identify many different kinds of knowledge if we are to fully comprehend and describe the transition of the naïve student to the conceptually competent physicist.

On the road towards becoming conceptually competent learners will exhibit failure of alignment in coordination classes. This could be an indicator to teachers on the progress of the conceptual journey of the learner. diSessa (2002) postulates that p-prims explain many wrong expectations that learners hold of the working of the natural world, and he continues to propose that they also explain phenomena like 'data fluidity' and the general richness and detail found in intuitive thought. When p-prims are in a relatively stable configuration for a particular class of contexts, they form 'macro-constructions' (which may be similar to Carey's notion of conceptual systems). However, diSessa (2002) sees p-prims as sub-conceptual, sub-theoretical or sub-model like. They are too small to be a macro-conceptual structure and he proposes that the development path from naïve p-prims and any of these macro-conceptual structures is "incorporation as a limited part" of an emergent complex knowledge system. This is why I incorporated p-prims on Level 1 of the hierarchy of mental entities (See Figure 2.3).

He proposes that coordination classes be a refinement of the idea of 'concept'. Theories are seen as even larger conceptual structures encompassing several related coordination classes, hence the inclusion of theories as the mega-conceptual structures in the hierarchy of mental entities as depicted in Figure 2.3. diSessa (2002) believes that language introduces important properties that may not hold in dominantly inarticulate knowledge systems. He further proposes that mental models should involve strong well-developed "substrate" knowledge systems such as spatial reasoning. It should also allow explicit hypothetical reasoning whilst involving only a small well defined class of causal inference (diSessa 1996). These mental models would require the ability to house hypothetical reasoning.

In the preceding sections I discussed the various views of conceptual development and conceptual change as found in the literature. What is evident is that there are certain agreements between all scholars that guided me in the creation of the hierarchy of mental entities as depicted in Figure 2.3. This hierarchy shows the relationships between all the various types of mental entities but does not adequately show how learning occurs. In the following section I discuss the possible learning mechanisms that allow for conceptual change to occur.

2.3.3 Mechanisms of Learning

Many processes have been postulated in the literature on how concepts are altered. One such mechanism known in the literature as ‘cognitive conflict,’ is proposed by Hewson and Hewson (1984); Posner et al. (1982); and Strike and Posner (1982), who were all early proponents of conceptual change theory. These are likely to have emanated from Piagetian theory. These authors proposed that before a child can acquire a new concept they have to be ‘dissatisfied’ with their current concept. This in turn is caused by a gradual increase of a child’s awareness of inconsistencies in the explanatory power or problem solving ability of their currently held concept (Ramsburg & Ohlsson 2016).

Other theories that offer descriptions of the mechanisms of conceptual change include the categorical shift theory, where a child’s current classification of a phenomenon is not viable and needs therefore to be reclassified under a different ontological category (Chi & Brem 2009); as well as the construction and revision of mental models (Vosniadou & Skopeliti 2013). Piaget (1977) described the imbalance between assimilation and accommodation, known as ‘disequilibruim’ as the driving force in cognitive development. Carey (2009) describes the processes involved in conceptual change in terms of the three processes of coalescence, differentiation, and Quinian bootstrapping (Ramsburg & Ohlsson 2016).

The processing of counter evidence is seen as an important aspect in theory change. Gopnik and Meltzoff go as far as to state that: “One particular critical factor [for theory change] is the accumulation of counterevidence to the theory.” (:39). Ramsburg and Ohlsson (2016) summarises the knowledge-as-theory perspectives:

> … the multiple knowledge-as-theory perspectives hypothesize different conceptual change processes, but they share the principle that those processes are triggered by negative cognitive outcomes. The latter include direct contradiction or refutation by someone else (e.g., teacher, text, etc.); inability to explain a phenomenon; mismatches between current beliefs and direct observation; unfulfilled expectations; failure to solve a relevant problem; and so on. In general, the difficulty in making a conception ‘work’ is the main condition that triggers the search for, or the construction of, a new conception.

They therefore refer to the construction of a new theory through falsifying the previous held theory by processing counterevidence as 'cognitive conflict'. Inducing cognitive conflict is seen by the proponents of the knowledge-as-theory perspective as a deductive reasoning tool whereby falsification and contradiction is a prerequisite for theory change to occur. The argument here is that a child will not attempt to alter existing concepts unless the application of the theory encounters difficulty in application to explanations or problem solving. This would lead to a waste in cognitive resources that could be put to better use. Teachers could therefore make use of cognitive conflict as a pedagogy deliberately to create conditions conducive to 'conflict' and thus anticipate (or plan) instead of waiting for these conflicts to present themselves spontaneously. These pedagogies range from simplistic strategies like merely informing a child that his currently held concept is incorrect (Ariasi & Mason 2014); or using demonstrations that exemplifies the flaws in the currently held concept by exposing its inability to account for presented evidence and failed predictions of these demonstrations (Lee & Byun 2012; Lin & Chiu 2007); to more complex methods including animations and simulations (Calik, Kolomuc & Karagolge 2010; Dega, Kriek & Mogese 2013).

The efficacy of these strategies is strongly debated in the literature. Strike and Posner (1992) reviewed intervention studies conducted in the 1980's and noted that the common finding from these cognitive conflict studies are that misconceptions are highly resistant to change. Limon (2001) reviewed the intervention studies of the 1990's and found that inducing cognitive conflict has positive benefits but noted that these benefits were smaller than expected and that in most cases these benefits were so small that it wasn't measurable and did not lead to a deep understanding of the new information. Heddy and Sinatra (2013) showed that the effects of cognitive conflict interventions were weak in comparison to other types of intervention.

The lack of substantial benefit shown by the research into cognitive conflict strategies led to studies that explored the influence of other factors on conceptual change which resulted in a more nuanced understanding of the processes involved in the conceptual change process. These studies included the influence that motivation and affect have on learning; individual differences within a sample of participants; metacognition; epistemological beliefs; and a person's intention to change (Cordova et al. 2014; Heddy & Sinatra 2013; Kang et al. 2010; Sinatra & Pintrich 2003; Trevors & Muis 2014; Zohar & Aharon-Kravetsky 2005). Ramsburg and Ohlsson (2016) argue that the lack of substantial benefit of cognitive conflict interventions shown by this wide range of studies falsifies the cognitive conflict hypothesis and states that “the difficulty of conceptual change must reside elsewhere than in conflict, or rather the lack thereof, between misconceptions and normatively correct subject matter.” It is therefore imperative that researchers also attempt to explain the mechanisms leading to conceptual change in terms that do not include cognitive conflict.

Xu (2016) proposes a thesis statement for her work on *preliminary thoughts on a rational constructivist approach to cognitive development* and posits that there are three major types of learning mechanisms as revealed through research on cognitive development; 1) conceptual learning driven by language and symbol learning; 2) belief revision through Bayesian learning; and 3) generation of new hypotheses through the organisation of factual knowledge using explanation, analogy, and thought experiments; can be considered as both rational and constructive. In describing which learning mechanisms are involved in developmental change, Xu (2016) identifies three learning mechanisms that are rational and constructive. She proposes that, 1) language is a medium that provides ‘’placeholder structures and constrains representational formats; 2) Bayesian inductive learning can explain how rationally combining evidence and prior knowledge leads to *belief revisions*, and that this in turn cumulatively leads to conceptual change; such change allows peripheral concepts to become core concepts; and 3) larger conceptual structures can be constructed by ‘learning by thinking’ tools to extrapolate from everyday life ‘data’ input as ‘evidence’. These three learning mechanisms may describe how new experiential concepts are formed spontaneously (according to Vygotsky 1978), but have to become ‘scientific’ theories through mediation and instruction.

Language, in the case of science education, would most likely refer to terminology and new vocabulary (and not limited to nouns), which provides the primer for the child that a new concept needs to be constructed. These new words (Level 1 on Figure 2.3) provide the placeholder structure which in itself does not provide the content of the concept but allows the child to create new mental symbols that leads to the acquisition of a new belief (Level 2 on Figure 2.3), a belief that is most likely derived from the acquisition of the relevant core beliefs from peripheral beliefs or proto-conceptual entities as described in the hierarchy of mental entities as depicted in Figure 2.3. During the revision of these beliefs we see a change in that some smaller beliefs could grow and become more central to reasoning. During development of concepts (Level 3 on Figure 2.3) some larger beliefs could become less prominent and make way for the new concept to take a more prominent place in the network of interrelated concepts. These initial belief revisions are caused by Bayesian inference mechanisms. Learning through thinking mechanisms such as analogy, explanation, mental simulation and thought experiments also facilitates new connections between previously unrelated concepts.

The preceding section presented conceptual change theory in a generalised manner using examples and citing authors who work in various field. Even though much of the relevant literature on conceptual development that has been cited thus far stem from the field of science in general it is necessary to also discuss conceptual change as it pertains to the selected topics of the vitalist theory of biology as well as observational astronomy. The following section describes the conceptual development of these two topics.

2.4 SCIENCE EDUCATION AND THE PREDICAMENT OF LEARNERS' BELIEFS AND THEORIES

One of the more pertinent challenges in science education is that the conceptual structures of children are vastly different, depending on their everyday life interactions and experiences (Gopnik & Metzhoff 1997) and at odds with those of scientists. If science education endeavours to improve the scientific literacy of children, it would be prudent for teachers to consider this and to make sure that they know about the processes of change in children's conceptual development; this means that they would know how children learn. I argue that teachers could benefit greatly by knowing about conceptual development and change in specific areas of science learning, such as how children build their knowledge of vitalist biology and of observational astronomy. The conceptual systems that adult scientists have constructed are incommensurable with the naïve conceptual systems of a child. Science education in schools has to foreground teaching that accounts for this incommensurability of concepts. I would suggest that the teaching of science could run the risk of individual concepts being distorted or ignored and left to fossilise, unless directly addressed.

Wiser and Smith (2016) argue that conceptual change in science education is complicated, due to some terminology in science having different normative scientific meaning than what is generally understood by the use of that term in lay conversation. These semantic 'misconceptions' may violate deeply held beliefs that jeopardises the

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stability of the conceptual system that someone holds. Some examples of these would include concepts such as *weight* and *mass*; *heat* and *temperature*; and *theory* and *opinion*.

Another challenge to bridge the incommensurability gap between naïve and normative science concepts lies in the constraints that children's own beliefs or presuppositions place on their ability to reform their conceptual understanding in such a way that will allow them to progress towards a normative understanding of the specific concept. Examples of these constraints will be discussed in the sections that follow, in which I will discuss examples of how conceptual development and conceptual change relate to specific domains in science education. For the purposes of this study I focus on the acquisition of a theory of biology referred to as 'vitalist biology' as well as the construction of a theory of observational astronomy. Both of these theories are included, or at least implied in the South African foundation phase curriculum and were the focus of the data for the study (see Chapter 4). Leading researchers in science education have also explored these topics.

2.4.1 Vitalist biology

Carey et al. (2015) argue that children start acquiring a theory of biology from around the age of five and that none of the conceptions related to vitalism are innate, as are a host of other 'core knowledges' such as an approximate number system, a theory of mind, and of agency. Vitalism can therefore be seen as an example of theory creation in young children. By studying many communities globally, it has been shown that children tend to journey on the conceptual road towards an adult conception of vitalism between the ages of five and 12. Vitalist biology is regarded as the first biological theory in the childhood years and underlies thinking about health, life and death (Zaitchik et al. 2016).

In this theory (in its normative form), environmental elements such as air, water and nutrients in the form of food are sources of vital energy necessary for the maintenance of all body parts. These vital energies must enter the body and disperse throughout the body in order to supply this (vital) energy to the various organs that are responsible for sustaining life, growth and health. All organs and metabolic processes are specialised, yet, cooperate in physiological structures known as organ systems. For the vitalist, that has come to understand the normative concepts of the theory of vitalist biology, life is understood to be the maintenance of homeostasis in metabolism and death to be the cessation of these bodily processes. The naïve vitalist is challenged by the incommensurability of her naïve concepts in that these underdeveloped conceptions do not yet show an understanding of physiology and anatomy and that most metabolic processes are unobservable. Naïve theorists typically view organs as containers. Zaitchik et al. (2016) argue that the acquisition of a normative vitalist biology theory is difficult and prolonged, due to the existence of a competing intuitive theory, 'the agency theory of living things'.

Scholars in developmental psychology, such as Piaget (1929), Carey (2015), and Zaitchik et al. (2016) have conducted interviews with children, probing their understanding of vitalism and have found that preschool children define being alive in terms of movement or the ability of an object to be active, a phenomenon that Piaget termed *animism.* Preschool children attribute life to inanimate objects such as the sun, wind and moving vehicles. They often also deny life to plants seeing that plants are not observed to be moving. The contrast between the concepts 'alive' and 'dead' is often mistaken with the contrasts of the concepts 'animate' and 'inanimate'. For young children, being alive is equated to being visible, real, existing or present. Their naivety goes further - they deem death to be the opposite of their conception of life. In other words, they equate death 'not being visible', to 'go away' or to 'stop doing things'. A more advanced concept of death is observed in some young children who understand death to be the end of existence. This, however, is not the same as the normative concept of death in that death is the cessation of life. These examples of preschool children's naïve concepts of vitalism show that they don't have any understanding of the body as a conglomerate of organ systems and biological processes that cooperate to maintain homeostasis and sustain life.

The incommensurable difference between a naïve vitalist biology and the normative one, lies in concepts that seem analogous in their semantics, yet allow for a nuanced differentiation such as the difference between the concepts of 'dead' and 'inanimate'. Dowker (2014) refers to this type of mismatch as 'linguistic conceptualisation'. Until children have learned the meaning of 'animate' and 'alive' and how the terms differ, they are likely to be guided by their (still limited) vocabulary and semantic categorisation. A deeper understanding would mean that a child grasps that only organic objects can be 'dead' as such objects had been able to have been alive before. A child would then also grasp that inanimate, or non-living, refers to objects that have never had the ability to be alive. For the naïve vitalist, life is identified with animals in so far as animals are fundamentally conceptualised as causal and intentional *agents*. It is only when conceptual change has occurred that children subvert this agency of animals with a more mature theory of vitalist biology.

Carey (2015) shows how the *mere accretion of facts* does not lead to the acquisition of a vitalist theory of biology: She employed the same battery of tests (see Chapter 3) on patients suffering from Williams syndrome, comparing the results to the results of studies done on children's acquisition of a theory of vitalist biology. Patients who suffer from Williams syndrome have a genetic disorder that leads to mental retardation, affecting the sufferer's ability to learn new facts, but does not hinder the sufferer's language ability, though. In these cases, they were able to retain factual information about life and the characteristics of living organisms, but did not achieve a vitalist theory of biology as the children from the other studies had done. Actually, these adult patients with Williams syndrome responded the same as normally developing four-year old children. From these results Carey et al. (2015) has argued that *domain general mental resources* play a role in the acquisition of a vitalist theory of biology - seeing that sufferers of Williams syndrome have severely underdeveloped domain general cognitive resources, despite their acquisition of language. Domain general resources for learning of science are crucial and have been the object of many studies (Section 2.5).

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2.4.2 Observational astronomy

Many authors of conceptual change have conducted research on children's understanding of astronomy. Although research studies on this topic in European countries as well as the United States and elsewhere are numerous, very little is known in the literature of South African children's conceptual development in the domain of observational astronomy. Studying the available literature on children's understanding of astronomical phenomena reveals that not only children, but also adults, have naïve conceptual systems and exhibit difficulty in explaining these phenomena (Pfundt & Duit 2006; Dove 2002; and Küçüközer 2007). Trumper (2006) has shown this to be the case for many primary school student teachers also. Such naïve concepts of observational astronomy are a result of many challenges in the teaching of astronomy. These challenges include 1) the representation of massive three dimensional objects in space, such as planets, moons and stars, using diagrams drawn on two dimensional surfaces such as blackboards and paper (Parker & Heywood 1998); 2) incorrect or misleading diagrams used in learning materials, where the text and diagrams do not correspond (Vosniadou 1991; Ojala 1997); and 3) the use of confusing terminology that puzzles children and lead to distortion of concepts within their conceptual systems (Parker & Heywood 1998).

The magnitude of the various celestial objects studied in astronomy is so large that many people have difficulty relating it to their own experience. This is understandable, given the small number of humans who have had the opportunity to travel to space and observe these objects and phenomena first hand. Educational aids such as simulations, animations shown in 3D cinemas or excursions to a planetarium remain limited as access to these resources are constrained by socio-political factors.

Several researchers have suggested possible solutions to these challenges by studying the impact of teaching interventions such as three-dimensional modelling, demonstrations, class discussions and projects (Bakas & Mikropoulos 2003; Trundle et al. 2007; Barnett & Morran 2002). I argue that these interventions will only prove fruitful once the individual learner's naïve concepts of observational astronomy have been identified and the teacher could design learning opportunities that address the deeply entrenched beliefs and presuppositions that constrain the development of a normative concept.

Vosniadou (2014) and her research associates have conducted several studies on the identification of the naïve concepts that children of varying ages hold in respect to their construction of mental models of the shape of the earth as well as their understanding of the day/night cycle. She posits that the conceptual development of observational astronomy is constrained by the *naïve theory of physics* that children construct, based on their own experiences. Vosniadou (1991) shows that such naïve theory of physics is based on a set of beliefs or presuppositions that children hold. She asserts that this has been observed in a multitude of international studies. Firstly, young children believe that space is arranged in an up/down configuration. For them movement of celestial bodies, such as the sun, occurs only on this 'vertical' plane. Secondly, they believe that gravity works in an up/down gradient which leads to the assumption that all objects that are not supported will fall downward in space. Therefore, if the earth is not supported, for instance, by a body of water or with soil, it will fall downward in this 'vertical' plane. The last presupposition as described by Vosniadou (1991) is that children believe that all physical objects are solid and cannot move autonomously. These presuppositions cause young children (and uneducated

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adults) to construct mental models of the cosmos that are incommensurable with the scientifically accepted explanations and models of the cosmos and might be the effect of their constraints, due to underdeveloped causal reasoning and causal inferences needed for Bayes net learning algorithms (Gopnik & Schulz 2004). Vosniadou and Brewer (1994) note that the typical intuitive theory or naïve mental model that is constructed of the earth is that it is flat, motionless and supported (either by water, sand, an elephant, four pillars, or a turtle, depending on contextual influences of the community); people live only on the top surface of the earth; and the sun and moon are located above the earth and cause the day/night cycle due to their movement. This is in contrast with the Copernican view of a spherical earth that orbits the sun, which Gopnik and Wellman (2012) would argue is learned through the mechanism of probabilistic causal models and Bayesian learning. Vosniadou (1991) posits that the child's framework theory of physics constrains the ability to change the naïve mental model of the earth to become commensurable with the normative view and that children often construct synthetic models that serve as an intermediate model whilst cognitively traveling towards the normative model.

When a child learns new facts that contradict his experience, such as the earth being a sphere as opposed to being flat, the child will attempt to assimilate the new information in a way that accounts for both sets of information. Vosniadou (1994) and her research associates have identified several of these 'synthetic models'.

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Rectangular or disc earth

Children who construct the naïve model of the earth represent it as a flat rectangle or disc that is supported by ground underneath and is surrounded by the sky and other celestial objects above. These models are consistent with the experience of the children and show little influence from the normative concept.

Dual earth

In this representation the child constructs two earths. The first being a flat earth on which people live and simultaneously a spherical planet suspended in the sky. This model allows the child to interpret and attribute the scientific information to another planet in the sky whilst not relinquishing their presuppositions based on their own observations and experiences and thus construct the second earth as the flat ground upon which people live. This model is an example of how accretion of facts leads to the assimilation of the new information into the previously constructed mental model and therefore creates a misconception as the new information is inconsistent with the naïve model.

Hollow sphere

The hollow sphere model is another synthetic model that resembles that of a fish bowl. The outer ‘layer’ is spherical which contains an inner ‘layer’ that is flat, deep inside the sphere. People live on top of the flat piece inside of the sphere. The hollow sphere model as well as the flattened sphere model are examples of misconceptions that are produced following partial changes in the subnetwork of beliefs and presuppositions. There is limited accommodation that occurs in the child’s conceptual system that produces these synthetic models. In order to construct the hollow sphere model the child suspends the belief that the earth needs to be supported and also releases only the earth from the belief that gravity works in the up/down plane. Vosniadou (1994) explains that the suspension of presuppositions is the mechanism that restricts the range of applicability of the presupposition and thus does not constrain a certain class of entities of a domain. The suspension of gravity in the up/down plane is the first step in conceptual change that a child undertakes on the journey towards the normative concept. The children who construct the hollow sphere model of the earth accept that the earth is suspended in space but still attributes the operation of gravity in the up/down plane to all objects on the earth. They can therefore not comprehend how people (and other objects) can be located on the surface of the sphere without falling off the surface. They therefore construct a level ground layer within the sphere on which all objects are found.

Flattened sphere

The flattened sphere has a level top and bottom where people live, but bulges at the sides. This model resembles a thick pancake like structure. This misconception is formed because of the suspension of multiple presuppositions such as the up/down plane that gravity operates on, but they do not suspend the belief that the ground that they walk upon is flat. Therefore, people will live on the flat surfaces of the earth. They flatten out the top and bottom of the earth to allow for both concepts, that of their naïve belief as well as that of the culturally accepted scientific explanation of a spherical earth.

These synthetic models act as intermediary models that could, with instruction, be reformed and revised by suspending or replacing presuppositions to become the normative model of the earth. It is difficult for children to construct the normative spherical model of the earth because this model violates deeply entrenched presuppositions of the framework theory of physics. Vosniadou (1994) states that children categorise the earth as a physical object as supposed to an astronomical object, and thus apply their presuppositions of general physical objects to the earth.

In addition to studying the mental models of the shape of the earth, Vosniadou and her research associates also studied the mental models children construct with regards to the day/night cycle. Vosniadou (1994) posits, as with the case of the shape of the earth, that children's framework theory of physics would constrain the development of a normative concept of the day/night cycle. She predicts the initial explanation that children would give for the day/night cycle in terms of the movement of the sun and its occlusion behind clouds and mountains. She further predicted that the process of conceptual change with regards to the day/night cycle would be gradual and that many misconceptions or synthetic models would be constructed based on the presuppositions that children hold in terms of their framework theory of physics. The initial model as constructed by children often range between a small range as children explain the day/night cycle either in terms of 1) the sun being occluded by darkness or clouds during the night; 2) the sun moves out into space along the up/down plane; or 3) the sun and the moon alternate by moving antagonistically. These initial mental models were often observed in children that also held the initial model of the shape of the earth. Vosniadou (1994) did not find any instance of a child that constructed a normative model of the day/night cycle who also constructed a flat earth model. The intermediate synthetic models that she observed mostly showed a geocentric disposition and ranged from the sun and moon moving up and down to the opposite side of the spherical earth; the sun and moon revolving around the spherical earth once per day. In some cases she observed a heliocentric model of the earth where the earth and the moon revolved around the sun every 24 hours or models where the earth rotates either up/down or east/west.

The presuppositions that originate from children's framework theory of physics also constrains the development of a normative concept of the day/night cycle caused by the rotation of the earth on its own axis. These presuppositions are the origin of the initial 'flat earth' model constructed by children, which, in turn, constrains the acquisition of the normative day/night cycle concept. Vosniadou's research on children's representations of the day/night cycle has revealed two factors of the process of conceptual change; firstly, that there appears to be a sequence in which concepts are acquired; and secondly, that the mental model constrains knowledge acquisition. My argument, therefore, is two-fold: It is imperative for the authors of science curricula to first establish in what sequence concepts should be taught throughout schooling; and teachers should then identify the mental models of the children as to inform their lesson design.

The following section discusses the impact of domain general resources such as executive functions on the development of domain specific concepts.

2.5 DOMAIN GENERAL RESOURCES IN THE DEVELOPMENT OF A THEORY OF VITALIST BIOLOGY

Determining the initial state of an infant's mind has long been the focus of research in developmental psychology and many challenges, specifically with regards to conceptual change, have been identified. One such challenge is to describe the processes and learning mechanisms involved in the acquisition and subsequent change of naïve concepts, or intuitive theories. Intuitive theories (as discussed in Section 2.3.2) are unique to specific domains and provide explanatory and predictive reasoning that allows children to make meaning of their observations and interactions with their environment. They establish frameworks for conceptual development. These framework theories constrain conceptual development. As shown in Section 2.4.2 the framework theories (or synthetic mental models) such as the earth being flat or the antagonistic movement of the sun and moon during the day/night cycle will constrain the development of other normative concepts such as gravity, the hemispheres of the earth, and seasonal changes.

With regard to this issue, I have argued that teachers should identify these domain specific intuitive theories that learners hold before designing lessons. Domain specific learning mechanisms can alter intuitive theories and drive conceptual development. Such mechanisms, however, are supported by a range *of domain general cognitive resources*. The domain general cognitive resources that hold value for conceptual change are executive functions (EF) which are cognitive processes that are involved in all cognitive work that demands novel and innovative thinking as well as non-automatic operations (Diamond 2013). EF's bring about cognitive actions such as planning, self-control, sustained attention and cognitive control. Thus, a young learner may have a sturdy domain specific intuitive theory that is not easily swayed, unless teachers have some idea of what else is involved in a child's cognitive activity – such as EFs.

Three core processes of EF have been identified: *Working memory* which comprise the processes responsible for sorting and updating information; *inhibition* which refer to processes responsible for constraining the activation of competing responses or conflicting representations; and *set-shifting* which are processes responsible for the flexibility to select from a multitude of relevant sources of information. Other processes, such as reasoning, deliberate and conscious planning and problem solving are thought to be combinations of the three core EF processes. Zaitchik et al. (2016) explains that EF plays a role in the academic success of children and posits that EF can be a greater indicator of school readiness than other factors, such as reading skills, maths skills or IQ. They explain this finding by proposing that children with better developed EF pay more attention at home and in school, which allows them to process more information than their peers, who have less developed EF. It is also possible that children with better developed EF are able to express what they know better than the other children. Well-developed EF are regarded as the driver of self-regulation in learning.

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EF competence can be used to predict the conceptual reasoning performance of children (Pagani, Fitzpatrick & Barnett 2013). EF are regarded as one of the essential components that allow for conceptual change, given that the mechanisms of conceptual change, such as 'bootstrapping' (see Section 2.3.3); the generation and evaluation of hypotheses; construction of mental models; and flexibly shifting between theories as a result of changing context, rely on processes such as working memory, inhibition and set-shifting. If we are to address the challenges that children face when learning, it is important that teachers have a nuanced understanding of not only the domain specific learning mechanisms, but also of the influence that EF would have on the ability of children to change existing theories. I argue that teachers who have this nuanced understanding of the interrelationship between domain general cognitive resources and domain specific learning mechanisms would be able to design learning opportunities that may hold more promise for conceptual change.

In science education, and of interest to this study, Zaitchik et al. (2014) conducted a series of tests to determine whether EF could predict a child's theorising of vitalist biology. The participants in these studies were asked to complete a battery of tests that attempted to identify their acquisition of a theory of vitalist biology as well as a battery of tests that attempted to describe the state of the participants' EF's development. It was found that the participants' score on the EF battery of tests significantly predicted their performance in the vitalist biology tests. Zaitchik et al. (2014) posit that children with higher EF scores will be able to advance more rapidly in constructing a theory of vitalist biology, given that EF supports theory-building learning mechanisms (in general). To further investigate the possibility that EFs support domain *specific* learning mechanisms, Bascandziev et al. (2015) conducted an intervention study that showed that individual differences in EF predicted children's benefit from theory-relevant (specific domain) training, such as for understanding of the characteristics of 'living objects'. In this study the authors conducted an intervention study that tested children, using the biology battery of tests (see Chapter 3) as well as a set of control questions on 'fun facts' in the subject of biology.

During the intervention the children were instructed on vitalism, using a curriculum designed to focus on basic anatomy and physiology of organ systems and how these systems function cooperatively to support and facilitate movement, health and growth. During the post-tests the participants completed the same set of biology and fun fact tests that were administered during the pre-test. In a subsequent post-test the participants completed EF and semantic fluency tasks as well as a receptive vocabulary test. The researchers found that the individual differences in EF predict the benefit the participants would gain from training that is relevant to the specific theory, in this case a theory of vitalist biology. The majority of participants showed improvement, some to a lesser degree, while some participants improved substantially.

From this study the authors argue that EF plays an important role in conceptual change and attribute the improvement in the participants' biology test scores to their ability to *pay better attention* during the training sessions. This is a case that exhibits the benefits of curriculum design that values the specific instruction of one of biology's 'big ideas' and shows that the mere accretion of facts do not lead to conceptual change. The South African foundation phase curriculum does not explicitly include the teaching of a theory of vitalist biology, just as it doesn't include the explicit teaching of

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a theory of physics and I argue for the inclusion of these theories in not only the school curriculum but also in the curriculum of teacher training programmes.

Other studies have attempted to determine what the role of EF is in the expression of an individual's theory of vitalist biology. Carey et al. (2015) hypothesise that EF are employed in the recall of vitalist *information* in that mature 'vitalists' would be required to inhibit their intuitive responses to a set of questions on animism and, thus, have a delayed response to these questions. Thomson-Shill et al. (2009) found that college students make the same errors under speeded conditions as their elementary school counterparts under non-speeded conditions. These errors include the attribution of life to inanimate objects and denied life to plants. It was also found that professors of biology show a delayed response to questions that require them to attribute life to plants compared to their response time to attribute life to a dog. This shows that intuitive theories remain in cognitive structures throughout our lifetime and require EF to inhibit the expression of these naïve theories in favour of the normative theory.

Zaitchik and Solomon (2008) found that the 'health' of an individual's EF also has an influence on the expression of vitalist biology. In a study that researched the understanding of vitalist biology of patients in the early stages of Alzheimer's disease, they found that impaired EF leads to a worse performance on the battery of vitalist biology tests. The same was found when comparing the performance of elderly subjects to young adults, showing that the degradation of EF leads to the inability to express a theory of vitalist biology adequately (Tardiff et al. 2015). From these studies it is evident that instruction, based solely on the subject content (such as fun facts of biology), without considering the influence of not only domain specific learning mechanisms, but also the associated domain general resources, such as EF, that support these mechanisms, could prove fruitless. On this view, I argue for the inclusion of EF along with domain specific learning mechanisms, and how these domains interact, in science teacher education training programmes.

Except for these domain general resources, language also contributes vastly to the development of concepts. It manifests at the intersect of general- and specific domains of cognition.

2.6 A LINGUISTIC 'GAZE' ON CONCEPTUAL CHANGE AND CONCEPTUAL DEVELOPMENT

Much of communication for learning takes place through language in both its tools of sounds and written symbols in a multitude of configurations. The sound system (phonology) is at first a child's only linguistic tool. Brink (2017) and Shingenge (2017) have shown how the written symbols of language (its orthography) depend on the child's knowledge and use of the smallest unit of phonology, namely its phonemes. Dehaene (2009), in neuroscientific studies, has found that these smallest units, when represented in a graphemic form of meaning, originate in what he has termed the brain's 'letterbox' and that these graphemes are the building blocks of children's reading competence. But, first they have to know the sounds of the language, which they learn by audition. I refer to these small soundbites, because there is evidence that phonological variables contribute to, among others, the farther development of the approximate number system (Dehaene 2011; Spelke 2000) with which humans are innately endowed. There is thus, already at birth, the probability that language as a sound system is a building block for language as a meaning system.

Gopnik and Metlzoff (1997) and Gopnik (2003) propose that during the interaction between young children and their social environment, children not only hear the individual sounds of their first language, but also learn words and parts of words and how these connect in phrases and sentences. They thus also learn, through interaction, how syntax and word order operate to make meaning beyond single words. Dowker and Nuerk (2016) go as far as saying that between the semantics of words and sentences, there is a linguistic concept that forms a pathway to different parts of a brain and so form concepts, such as 'water', 'mother', food' 'walk' or 'eat'. My argument is that this is almost exactly how children develop concepts from their natural environment. They encounter phenomena, events and ideas, they hear spoken language that refer to these and they begin to connect words with concepts. Vygotsky (1986; Ragpot 2013) referred to this phenomenon as the 'place' where 'scientific concepts' and 'spontaneous concepts' meet. Henning (2012) has argued that the learning of what appears to be 'senseless' words and sentences, may ultimately coalesce into understanding and the 'autonomy' of the words as authentic symbolic representations of their meaning (in the scientific sense). Her study of adolescents' use of terminology to express their conceptions of 'light' as a physical phenomenon showed how the words and sentences came to meet after five years of high school science education.

Words act as ‘placeholder’ structures in conceptual development (see Section 2.3.2) and provide a substrate for the semantics of the concept in which to grow. Xu (2016) reviews three types of mechanisms of learning and developmental change and discusses language learning as a vehicle for conceptual change. These learning mechanisms have been discussed in Section 2.3.3. She argues that infants’ initial knowledge needs to be in the correct format for language learning, otherwise some developmental changes have to occur. She states that infants begin acquiring the semantics of language toward the end of their first year and that the various parts of language provide these ‘placeholder structures’ that enable conceptual development. Xu (2016) proposes that the core knowledge systems rely on language to become discrete, but cannot achieve this unless deep conceptual change occurs. This requires children to construct new resources to represent concepts and eventually emerge as a fluent speaker of the language with vocabulary and structures in concert with, for instance, the discourse of science (in the home). Katz and Fodor (1963:171) describe a fluent speaker’s mastery of his language as an individual who “can produce and understand the sentences of his language, including indefinitely many that are wholly novel to him.” The individual becomes a producer as well as a consumer of language that expresses their conceptual understanding in novel ways.

The role of language in conceptual change has been debated in the fields of linguistics, philosophy, and psychology (Boroditsky 2011; Carey 2009; Fodor 1983; Whorf 1956). Carey (2009) distinguishes between two broad positions on the influence that language learning has on concepts. She first describes language learning that allows children to represent concepts that they previously could not represent. This she terms *Quinian (or strong) linguistic determinism*. The second, she describes as language learning that clarifies the concepts that children already hold and terms this as *weak linguistic influence*. Gentner and Goldin-Meadow (2003) refer to this as “language as a lens” and as “language as a tool” respectively. Language that provides novel ways to represent the world and by implication, enables learning mechanisms such as ‘bootstrapping’, is seen as a new lens through which to make sense of the world; or language has the ability to slightly alter representations that already exist.

Levine and Baillargeon (2016) adds a third position to the debate and argues that regardless of the influence that language has on concepts, whether it is weak or strong, is influenced by the amount and quality of *language input* that the child is exposed to. They posit that this could affect the timing and nature of the influence that language learning has on the relevant concept. They term this “language as data”. These three positions present a generic approach to the question of how language influences concepts, but Carey (2009) argues that no one answer would be sufficient to explain the totality of language’s influence on thought as language seems to play multiple roles in learning. She proposes that each case of conceptual development be studied separately to establish how language influences each specific domain.

In their review of Carey’s work on numerical development Levine and Baillargeon (2016) found strong empirical support for Carey’s claim that language serves as a lens that makes possible new representations that children could not previously represent due to the incommensurability of the language associated with conceptual system 1 (see Section 2.3.2). They also found evidence that language sometimes serves as a tool that enhances existing representations. They furthermore emphasise that access to relevant language input – language as data – can influence the course of children’s conceptual development. These authors are in agreement with Carey, that research into the contribution of language on the conceptual development should focus on specific cases as to advance our understanding of conceptual development in general. I support this view and recommend that the same be done for specific cases in science education in South Africa.

A challenge in South Africa, as with many developing countries, is the great diversity of languages spoken by its citizens. South Africa has eleven official languages, but the language of teaching is mostly English and Afrikaans from Grade 4 onwards. Some of the African languages like isiZulu, Sesotho, and isiXhosa are chosen as the medium of instruction for the foundation phase only. Xu (2016) explains that even though the syntax of various languages may differ, the semantics associated with the words and phrases should align to represent the same concept. The concept of photosynthesis should be the same regardless whether it is expressed in Mandarin, English, or isiZulu. The challenge for science education lies in underdeveloped scientific terminology in the African languages. This results in children learning scientific vocabulary only in English but the rest of the conceptual construction occurs in their home language. This ‘code switching’ (or ‘interlanguaging’) requires the use of added cognitive resources, both general and specific, which creates a disparity between home language English speakers and children who use English as an additional language.

I argue that if we are to investigate the role that language plays in conceptual development for science education in South Africa, we need to study the individual cases with regard to 1) each content domain of science and 2) in every language that these content domains are taught. The scale of such an investigation would be enormous, but still wouldn't address how teachers would be able to use the knowledge generated from such studies. Given that each context is unique, teachers would need to be trained to determine the role that language plays in the conceptual development involved with each of their science lessons, and design appropriate learning opportunities using the identified language elements to improve the probability that conceptual change would occur.

Thus far, this chapter included discussions of various aspects that enable conceptual development, but does so largely in a universal sense. Sections 2.7 and 2.8 are dedicated to 'geosocial' context-specific matters that informed not only my thinking, but also the design of the study. When studying science education in a primary school in Soweto, Johannesburg it is important to sketch the background and current state of the science education landscape, in particular that of science education in the foundation phase.

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2.7 THE STATE OF SCIENCE IN THE FOUNDATION PHASE

When studying the South African foundation phase curriculum it is evident that the science content is to an extent 'hidden' and not made explicit as is the case for the literacy and mathematics content (South Africa. Department of Basic Education, 2011). The topics that can be categorised as science concepts or science knowledge can be found spread thinly within the 'beginning knowledge' strand of the life skills subject. The curriculum that preceded the current policy gave foundation phase teachers much more guidance in teaching science as this curriculum had a separate policy on science education which had a strong focus on learning through science process skills and allowed teachers greater autonomy in developing lesson topics by using the curriculum documents in tandem as tools to design lessons (Ross & Cartier 2015). The current curriculum provides very little guidance on how to teach the prescribed topics and skills.

The life skills subject is viewed by many teachers as less important when compared to the mathematics and literacy subjects (du Preez 2016) and several authors (Krogh & Morehouse 2014; Patrick & Mantzicopoulus 2015; Slavin et al. 2014; Smolleck & Nordgren 2014) suggest that the low priority given to science within the life skills curriculum may lead to science as a subject being marginalised even further. This matter is not unique to South Africa but is witnessed in many countries which do not give much precedence to science in their curricula for the early grades (Albion & Spence 2013; Campbell & Chittleborough 2014). Complicating the matter of teaching science in the foundation phase is the fact that the life skills curriculum is not available in many of the African languages including isiZulu which, apart from English, is, colloquially, the most widely spoken language in the country. This presents a challenge for teachers who are required to teach using these African languages as the formalised language of instruction. The current curriculum does not offer much guidance on how to teach the 'beginning knowledge' part of the life skills curriculum and expects very little autonomy from the teacher.

The curriculum does expect that the teacher teaches the life skills component in an integrated fashion that focuses on making learning reflect life so that the learners can see the value of why it is taught. It requires that content and skills be presented in such a way that learning is relevant and meaningful. Unfortunately, the curriculum does not provide sufficient guidance on the types of activities, nor does it provide guidance on how science should be integrated with the rest of the curriculum (Beni, Stears & James 2017). I argue that if the curriculum expects of teachers to integrate science in this fashion it should also be written in such a way as to give clearer guidance on how to achieve these objectives. The current Grade R curriculum does not even represent any science concepts in ways that conform to the criteria of scientific concepts which includes simple scientific concepts.

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Compounding the challenges presented by the current curriculum structure, foundation phase teachers are reluctant to teach science (Abell & Roth 1991; Appleton 2003; Mellado, Blanco & Ruiz 1998; Smith & Neale 1989) and do not feel confident in teaching science and site their teacher training programmes as being inadequate in preparing them as teachers (Sibaya & Sibaya 2008). Southerland, Sowell and Enderle (2011) states that when teachers do not feel confident it often leads to avoidance behaviour and Appleton (2008) posits that this lack in confidence causes teachers to teach science in the same manner that they would teach other subjects. Science learning is complex because naïve concepts about the natural world are not easily changed to scientific accurate concepts (Smith 2007; Vosniadou 2007; Carey 2000; Chi, Slotta & de Leew 1994; diSessa 1993). Therefore, science teaching requires a robust PCK of its own. What is typically observed in foundation phase science lessons is a teacher centred approach and in some cases include hands-on activities but these activities seldom build connections to science ideas or practice (Roth 2014).

The lack of confidence of the teacher can be attributed to their lack of science content knowledge (Akerson & Flanigan 2000; Appleton 2008; Borko 1993; Smith & Neale 1989; Waters-Adams 2006) and their limited background in science often leads to a negative attitude towards teaching science (Riegle-Crumb et al. 2015; Smolleck & Nordgren 2014; Tenaw 2014). To remedy this Smolleck and Nordgren (2014) as well as Kazempour and Amirshokoohi (2013) suggest that teachers should first experience positive science learning themselves if they are to improve their confidence in teaching science. It therefore, places the onus on teacher training institutions to ensure that pre-service foundation phase teachers experience positive science learning opportunities during their training.

Most South African foundation phase teacher training programmes include very little science in their curriculum. Most programmes only teach science content for one semester and mostly entail the learning of science content. In order for teachers to teach science adequately they not only require science knowledge across all content areas but also need a good understanding of the nature of science as well as PCK grounded in methodology unique to the teaching of science (Nowicki, Sullivan-Watts, Shim, Young & Pockalny 2013; Shulman 1987; Schneider & Stern 2010; Qablan & DeBaz 2015).

The policy that informs the training of teachers, the minimum requirements for teacher education (MRTEQ), states the types of learning needed for teachers are "associated with the acquisition, integration and application of knowledge for teaching purposes" and requires of teachers to obtain "specialised PCK, which includes knowing how to present concepts, methods and rules of a specific discipline in order to create appropriate learning opportunities for diverse learners, as well as how to evaluate progress." (South Africa. Department of Higher Education and Training, 2015). I argue that many foundation phase teacher training programmes fall well short of these requirements when training teachers in science education. If we are to train teachers who can sufficiently teach science we need to ensure that the teacher training curricula make connections between the theoretical components of teacher education and the practical realities of the classroom whilst encouraging critically reflective practices. This could enhance the student teachers' professional practice as well as their self-efficacy, values and views as transformational science teachers (Lewis, Dema & Harshbarger 2014).

South Africa is experiencing a shortage of professionals with mathematics and science skills to meet the workforce requirement of industry, commerce, health and education (Evans 2013; Hwenha 2013; Spaull 2013). If we wish to stimulate interest in science as a possible career choice for learners and cultivate scientifically literate citizens, we need to first introduce science earlier in the curriculum in a more robust manner and secondly equip the foundation phase teachers to teach science in such a manner that will ensure that children have science knowledge, science process skills, values and attitudes that will enable them to manage in a scientific and technological world.

If we are to improve the state of foundation phase science education it would serve a pragmatic purpose to study cases from other countries whit a proven track record of excellence in science education. For the following section I discuss the success of Finnish science education.

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2.8 EXCELLENCE IN SCIENCE EDUCATION: FINLAND AS ROLE MODEL

To discuss examples of exemplary science education, one also has to discuss it in tandem with the education system in which it is lodged. Education systems embody core values and aspire to specific educational ideals. In a comparison of the science curriculum in China and in Finland, Wang et al. (2018) explain that the Chinese curriculum resembles that of the Anglo-American curriculum tradition and Finland's curriculum resembles that of the European-Scandinavian *Bildung-Didaktik* tradition. Both these traditions offer theories and practices that are prevalent in western countries, but differ in their philosophical goals. Nevertheless, although these traditions share learning and teaching goals, they differ in their aims for teaching and learning, the roles of teachers, and the function of the national curriculum (Wang et al. 2018).

I agree with Wang et al. (2018) when they argue that the Chinese curriculum has much in common with the Anglo-American tradition, which has a strong focus on standardisation and accountability in the education system and includes some practices that continue to appear as 'transmission of knowledge', the learning of skills and methods, problem-solving, inquiry and so forth. This is in some contrast to the aim of the *Bildung-Didaktik* tradition of holistic education of the individual. The curriculum and teaching plans of the Anglo-American tradition are detailed and well-articulated and expects of schools to achieve the stated objectives of the 'common core' and ensure that all the content included in the curriculum is covered. Teachers' performance is measured by assessing the learners' learning outcomes and could result in teachers becoming passive agents of the education system who are expected to follow the curriculum and implement its requirements rigidly.

By contrast, the *Bildung-Didaktik* tradition aims at empowering citizens to be capable of participating in society whilst reconstructing society and living successfully (Autio 2013). This tradition values the teachers' academic freedom and respects their autonomy, while emphasising the need to converse with learners about the subject matter in every lesson. These teachers are considered to be professional experts and entrusted with complete freedom to implement the curriculum and their performance is not only measured based on the learning outcomes of the learners. This is possibly a leading factor in the Finnish success evident in international benchmarking assessments such as PISA 2015 (OECD 2018).

It could be argued that most countries' school curricula lean closer to one of these traditions than the other and the question arises which one of these traditions would serve its citizens best in the 21st century. I argue that the aim of education should be to prepare people to be self-sufficient, participatory citizens of an ever changing global community. This view aligns closer to that of the *Bildung-Didaktik* tradition which I believe to be the most appropriate philosophy to adopt if we are to adequately prepare learners for life in the 21st century. Globally this topic has become an important subject of discussion when considering educational reform and international organisations such as the European Union value education as the means by which citizens would acquire the key competencies to live in a rapidly changing world (Voogt & Roblin 2012). These competencies do not only require the enrichment of the cognitive domain, but also promotes the acquisition of skills, values as well as knowledge. Incorporating these competencies in existing curricula presents many challenges which several countries have attempted to address by constructing frameworks for the teaching of these competencies.

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Finland and China have both recently introduced their frameworks and I briefly summarise the aims of both these frameworks. The reform of the Chinese curriculum aims to cultivate the individual as a whole by emphasising core competencies in the areas of learning to learn; healthy living; citizenship; practice, creativity and innovation; cultural heritage; and scientific literacy. Finland has framed their core competencies as thinking and learning to learn; cultural competence, interaction, and self-expression; managing daily life and taking care of yourself; multi-literacy; competence in information and communication technology; working-life competency and entrepreneurship; participation, involvement and building a sustainable future (Finnish National Board of Education 2016). These focus areas are applicable in all subject areas and aligns greatly with the aim of developing *Bildung* (German for the whole person). This then begs the question of what the role of science education is in supporting learners in acquiring these 21st century competencies.

Science provides intersects for the acquisition of core competencies as the nature of science as well as scientific literacy addresses many of the focus areas as described by the Chinese as well as the Finnish frameworks. In both these countries science is taught as an integrated subject in the foundation phase and includes subject domains such as physics, chemistry, biology, geography, technology and engineering. This is in stark contrast with the South African curriculum (see Section 2.7) that does not include science to such a degree.

The Finnish approach to education has proven worthy as example of excellence, given that their reform of education policy as the key to social and economic development has led to them being regarded as one of the most developed countries. Sahlberg (2007) attributes the success of the Finnish education system to an accumulation of various education policy reforms that did not follow global trends such as standardisation and centralisation of education; greater focus on numeracy and literacy; and consequential accountability. Instead Finland opted for flexibility and loose standards facilitated by a decentralised education system; broad learning combined with creativity; and intelligent accountability with trust based professionalism. Schleicher (2006:9) suggests that the success of the Finnish education system can be attributed to, among other factors, “the capacity of policy makers to pursue reform in ways that went beyond optimizing existing structures, policies and practices, and moved towards fundamentally transforming the paradigms and beliefs that underlay educational policy and practice until 1960’s.” Sahlberg (2007) argues that several factors of the Finnish education system contributed to the good performance of its schools and learners. These factors include 1) the same basic school education for all children; 2) well trained teachers; 3) intelligent accountability; 4) a culture of trust; and 5) sustainable leadership.

The Finnish science curriculum supports the greater education policies of the country by aligning closely with the *Bildung-Didaktik* tradition by including more than just science knowledge and science skills commonly referred to as 'scientific literacy' and 'scientific inquiry'. Key words such as 'well-being'; 'community'; and 'sustainable development' are prevalent in Finland's science curriculum reflecting the broader aims and values of this knowledge society. Throughout the Finnish science curriculum emphasis is placed on adding an affective layer to that of knowledge and skills. Wang et al. (2018) show two examples of the additional focus on values and morals by comparing the Finnish science curriculum to that of the Chinese science curriculum and show that ICT is described as a tool for learner presentation in the Chinese curriculum, while the Finnish science curriculum mentions the ethical use of ICT. Secondly, they describe the category of communication, for the Chinese, has a greater emphasis on the knowledge and skills to communicate information while, for the Finnish, the communication of emotion is of import. For the Finnish, the science curriculum forms part of the greater educational whole and strives to aid in the development of citizens who can independently and voluntarily participate in their society while the science curriculum in China is for the benefit of the individual who becomes a tool in building the society. Modern science education should not only strive to cultivate the mere increase of science knowledge but should also cultivate reflective citizens who grasp the nature of science and who are intrigued by the ideas of science which in turn enables these citizens to engage with science related challenges at both the personal and greater community level (Ferreira & Morais 2013).

The inclusion of a more robust science teacher education curriculum in foundation phase teacher education programmes that focus on not only the learning of science content and associated pedagogies, but also on the importance of developing scientific literacy that can be applied to solving personal challenges as well as the challenges of the community, holds the potential to bolster the aim of preparing children for life in the 21st century. The South African foundation phase teacher is considered a generalist teacher and is required to teach content from a wide range of disciplines and subjects. I argue that these teachers are positioned optimally within the education system as to introduce and establish scientific reasoning and problem solving. Frost (2010) identified types of knowledge that science teachers need to possess in order to adequately teach science. These include content knowledge, epistemological knowledge, knowledge of teaching and assessment strategies, curriculum knowledge, knowledge about student learning in science, attitudes toward science as well as attitudes toward their own professional development. These types of knowledge align with the knowledge types for teachers as stated by Shulman (1986) and presents a unique opportunity to integrate these knowledge types in foundation phase education programmes given the need for a more general PCK of foundation phase teachers. I argue that this integration of science as well as the inclusion of cognitive development and conceptual change in foundation phase teacher education programmes could assist greatly in training teachers competent in fostering the *Bildung-Didaktik* traditions.

2.9 CONCLUSION

From the discussion of conceptual change and conceptual development it is evident that change within conceptual networks are complex and require of teachers to nit only know science content and associated pedagogies but also a nuanced understanding of the mechanisms involved in establishing conceptual change. For foundation phase teachers this holds many challenges and would require intensive intervention, in policy as well as in practice, to empower them with the needed skills to design and execute lessons that would be of value to the development of science concepts of their learners. Before these interventions can be undertaken we first need evidence that foundation phase learners' conceptual development aligns with those of children as presented in international literature. The remainder of this report describes my attempt at designing and executing a study that would confirm whether the conceptual development of children in the foundation phase, of one particular South African school, indeed align with what is known from international studies.

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CHAPTER 3

DESIGN OF THE STUDY

3.1 A CASE OF EARLY GRADE LEARNERS' THEORIES

I conducted this study as a practitioner researcher (Petker 2018; Colwell & Richardson 2002) who wished to investigate, a part of my practice as a teacher educator, the theories that young children hold. Because I train teachers for the early grades, I advise them to read up on what leading science education researchers write about young children's learning. However, I realised that we train future teachers without knowing much about the children who are in the primary school which serves as their 'pedagogical laboratory' (Henning et al. 2015; Gravett & Ramsaroop 2017) on the university campus. Thus, to ensure that they "know the learner" as part of their foundation for pedagogical content knowledge (PCK) as described by Shulman (1986, 1987), I embarked on a study that could yield some empirical knowledge of what the foundation phase children typically know.

I designed the case as a "bounded system" (Stake 2008, 2013; Yin 2013), consisting of the young learners in their school context, specifically their expressions of understanding about observational astronomy and vitalist biology. The unit of analysis defined the boundedness of the system, in which I wanted to recognise that the children's (individual) understanding is also nested within a sociocultural and educational reality that refracts their conceptual development in specific ways (Figure 3.1). This is the reason for utilising activity system analysis (ASA) as an analytical and interpretive device. This tool is discussed in Section 3.10.

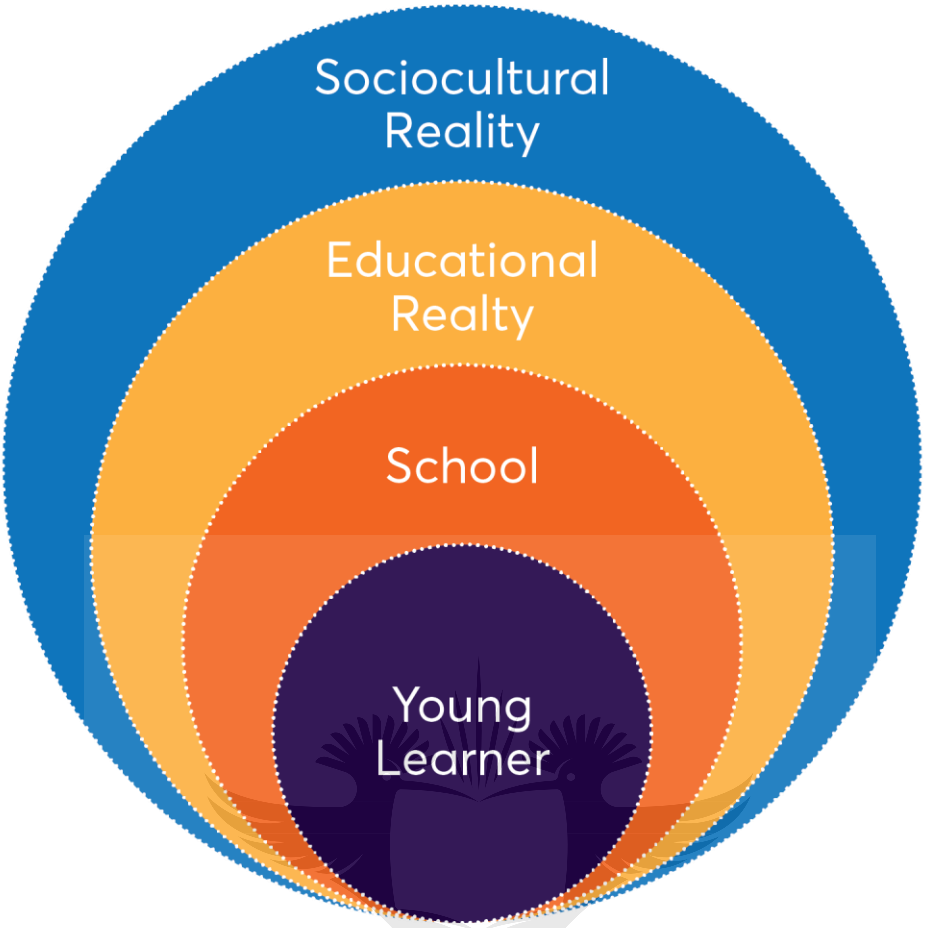

Figure 3.1 A child's learning in a specific sociocultural- and linguistic reality

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In planning the study I contemplated whether I should assess the children's knowledge in conventional classroom assessment mode, but realised that the modality would have to include some experiential investigation and also some elements of *Homo faber* – the children would have to not only talk about the topic, but should also see some demonstration that could grip their attention while, additionally, also make an artefact to explain their conceptions and their theories. I then opted to include science events and clinical task interviews as modality for data collection. I had by then defined the boundaries of the case; it would be about the unit of analysis (the children's conceptions) and related data that would reflect their current knowledge, focusing on the research question from different angles.

The research question that was posed at the outset of the study was about early grade children's conceptions (thus also their theories) of observable astronomy and vitalist biology. To address the research question and the problem as described in Section 1.2, I needed to develop a means to gather and interpret data that would provide insights into what Carey (2009) refers to as ‘conceptual systems’ of the foundation phase learners – in this instance, the systems that children had constructed about astronomy and living organisms. I also wanted to find out if there had been any progress in the forming of these science concepts during three years of learning and development in the foundation phase from Grade R to Grade 3. The research question firstly asked what learners in the foundation phase know about these two topics and, secondly, if there are any differences or similarities in this knowledge throughout the grades of the foundation phase. To this end I designed a study in which I could investigate the topic by way of qualitative methods to obtain rich, descriptive data. Specific benefits of qualitative data are summarised by Miles and Huberman (1994):

> Qualitative data … are a source of well-grounded, rich descriptions and explanations of processes in identifiable local contexts…. Then too, good qualitative data are more likely to lead to serendipitous findings and to new integrations; they help researchers to get beyond initial conceptions and to generate or revise conceptual frameworks. Finally, the findings from qualitative studies have a quality of “undeniability”. Words, especially organized into incidents or stories, have a concrete, vivid, meaningful flavour that often proves far more convincing to a reader – another researcher, a policy maker, a practitioner – than pages of summarized numbers (Miles & Huberman 1994:1).

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For this study it was important to obtain data that could generate insight into the participants’ evolving conceptions and get beyond initial ones - my own as well as those of the children. To explore their understanding, and to ultimately interpret it, I needed to describe the conceptual framework within which I was lodging the study. I was hoping to find some ‘undeniable’ evidence of what the children’s theories of two parts of their natural environment are. The reasoning for the design of the study, specifically the approach to data analysis, was guided by an overview of the qualitative data analysis process as suggested by Miles and Huberman (1994, 2013). I was attracted to their systematic rendering of how to plan this type of study, also as the original edition’s revised version in 2013 sets it out. In Figure 3.2 I show an adapted and simplified version of their qualitative data analysis process.

Figure 3.2: The flow of the research (adapted from Miles and Huberman 1994:308)

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The figure illustrates a sequence of, as well as the relationship between the various aspects of a research study. The unit of analysis (Trochim 2006) of the study, namely foundation phase children's notions of observational astronomy and vitalist biology, provided a platform for the combination of data. The conceptual framework for this focus has been discussed in Section 2.3 and describes how conceptual development and conceptual change theory have guided my thinking about how children formulate/express science concepts.

What needs further discussion, however, is the choice of analytical framework for the study. I discuss cultural, historical, and activity theory (CHAT) as the 'gaze' (Wardekker 2008) on the sociocultural system in which the child participants live and learn (see Section 3.10). First I argue that a sample of specific children, who speak isiZulu, were selected for the second phase of the study, while the first phase included entire cohorts in the school, where Sesotho is also a medium of instruction and where linguistic 'code-switching' is a regular phenomenon.

3.2 SAMPLING

One of the challenges of designing qualitative research is that the researcher could find himself attempting to describe a phenomenon so comprehensively that no significance can be found in the description of the phenomenon (Merriam 2016). It is necessary to set clear boundaries when conducting a qualitative case study, to set a particular focus, and to reduce the *grain size of a study to fit the required scope.* Miles and Huberman (1994) regard decisions about design as a form of 'anticipatory data reduction', as these decisions constrain later analysis by excluding certain relationships and variables and including only the variables and relationships that are of significance to responding to the research question. In this view, qualitative study designs are seldom copyable, as every qualitative study should be uniquely designed to answer the research questions of the particular study in a very particular way, especially if the 'grain size' is small. For replicability purposes the 'chain of evidence' of research is recorded and the reliability is strengthened, though. Decisions concerning the sample of an inquiry is one aspect of a study that assists in binding and focussing the research. Miles and Huberman (1994:27) say qualitative researchers "usually work with small samples of people, nested in their context and

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studied in depth…" In this section I describe the people who participated in the study, as well as their context.

A township school in the South West of Johannesburg was purposefully selected as research site, given the close relationship between the management of the school and the university research centre where this study is nested. The school is situated on the university premises with the aim of monitoring the integration of teaching theory and practice as well as researching all aspects pertaining to schooling, i.e. the learner's academic development, teacher mentoring and the development of student teachers' PCK (Loukomies et al. 2018). The school is a research-based teacher education site as well as a fully-fledged public primary school. Classroom populations comprise learners, student teachers, as well as teachers from the local community. The primary languages spoken in the community is IsiZulu and Sesotho, - hence, the creation of two classes per grade in the foundation phase, each divided based on the language of teaching being either isiZulu or Sesotho. English is the language of teaching as from Grade 4; however, certain subjects, like mathematics are taught in English (with translations and code-switching) from Grade 1. Learners in this school come from a modest, relatively poor socio-economic background with many parents being informally employed or holding working class jobs. The school model is based on the Finnish practice school idea, where student teachers obtain practical knowledge in authentic classrooms under the supervision and mentoring of an experienced mentor teacher (Gravett & Ramsaroop 2015). Permission was granted to conduct interviews with the foundation phase learners of the school and do perform the science demonstrations.

Qualitative sampling is often theory driven (Miles & Huberman 1994; Henning, Van Rensburg & Smit 2004) and should be informed by the conceptual framework of the study. To select 'desirable participants' I considered both the conceptual framework of the study and also considerations of convenience in sample selection (Henning, van Rensburg & Smit 2004). Given that conceptual change is described as being resistant to change and often requires time (Ozdemir & Clark 2007), the decision was taken to sample children who have not been exposed to formal schooling in the foundation phase, as well as children who have had three years' experience in the foundation phase and would soon be progressing to the intermediate phase of schooling. My reasoning was that three years of schooling may show conceptual change. Hence, the Grade R and the Grade 3 cohorts were selected to participate in this study, which can be regarded as a cross-sectional design. Data were collected at two separate time points. The first collection was during classroom interviews presented as a series of science demonstrations and the other was individual task based interviews, conducted in the school's experimental classroom. The initial classroom interviews were conducted in one Grade R classroom (n=24) and one Grade 3 classroom (n=29). A total of 20 children (Grade R n=10; Grade 3 n=10) were randomly selected to participate in the individual task-based interviews (see Appendix C). All participants were enrolled in the isiZulu classes, necessitating the use of translators to assist with conducting the interviews. Most participants, especially, from the Grade 3 sample, were able to express themselves in English but did have the option to communicate in isiZulu if they so wished.

3.3 INSTRUMENTS FOR DATA COLLECTION.

In order to collect data one needs appropriate instruments that would capture data optimally. In a study such as this thesis, the tools for data collection were custom-designed. The interviews, following on the science demonstrations, were a hybrid of the stimulated recall method, in that children were asked about the event in which they had participated immediately before the interview (Moustakas 1994). I decided on this type of interview to gain a deeper understanding of the participants' experience of the science demonstrations and thereby capturing aspects of their 'theories' and their conceptual structures. In these interviews the children, as participants, could 'speak for themselves' (Babbie & Mouton 2010). For the design of the interview protocols for both phases of the fieldwork, I drew on the work of Carey (2009) and Vosniadou (1994) to inform the protocols. My reasoning was that the questions in the protocol could help the children to focus on the topic. Carey (2015) and others (Zaitchik et al. 2016) used a battery of tests to elicit the 'state' of children's theories of vitialist biology from the participants. As explained in Section 2.4 this battery of three tests aims to describe the theory of vitalist biology that an individual holds. First, these authors use the 'animism interview' (Carey 1985b; Larendeau & Pinard 1962; Piaget 1929) to probe the meaning of 'alive' and to establish what the individual categorises as a 'living thing'. Following these open-ended questions participants are asked to judge a series of named entities - whether these are alive or not. The second test is a 'death interview' (Carey 1985b; Slaughter 2005; Slaughter & Lyons 2003; Zaitchik et al. 2013) that probes the difference between entities that are alive and entities that are considered dead. The

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third task, the body parts interview (Carey 1985b; Slaughter 2005; Slaughter & Lyons 2003), asks the participants to name the position and function of a series of organs and other body parts. The participants are also asked to predict what would happen if a person did not have a certain organ or body part. For both interview protocols, I decided against using the exact same battery of tests but rather decided to design a series of questions similar to those of the biology battery that could yield similar responses. Merriam (1998), cautions researchers that rigid adherence to predetermined questions may restrict researchers from gaining deeper insights into the perspective of participants. However, the interview protocols in the study remained constant across the various participants for reasons of reliability.

For the purposes of this study I aimed for more spontaneity and openness and decided to let the children elaborate on their answers as freely as possible. For the first phase of the fieldwork, children were presented with familiar objects, similar to those of the first task in the biology battery, and asked whether the object is alive or not. The children were then asked to explain their answers. In the second phase of fieldwork, a set of task-based interviews were designed in the same vein as Piaget (1929) did with his early research, using clinical interviews. In these task-based interviews, the young learners were asked to group a set of 20 pictures, each representing either an animal, plant or abiotic factor such as soil, air or water, into two groups. The rationale was that children who held a normative theory of vitalist biology would recognise the differences between biotic and abiotic factors and subsequently group the pictures from the same categories together.

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A similar approach was followed in the design of the interview protocols for the observational astronomy tasks. Vosniadou and colleagues (Vosniadou & Brewer 1992; Vosniadou 1994; Diakidoy, Vosniadou & Hawks 1997) studied children's naïve frameworks of observational astronomy by asking a series of factual and generative questions. The factual questions included questions that required of participants to provide information that would inform the researchers of their exposure to theoretically important facts, but did not require the participants to apply these facts in a specific context. Examples of such questions would include "what shape is the earth?" and "what colour is the earth" etc. The generative questions expected the participants to apply their knowledge to a specific context and provided the researchers with opportunities to gather information about the participants' underlying conceptual structures. Examples of these questions are, "if you were to walk for many days in a straight line, where would you end up?" and, "Would you ever reach the end of the earth?" These questions required the participants to generate a mental representation of the earth which would inherently contain information about its shape and relationship with other celestial objects. In this study I also used a combination of factual and generative questions to elicit the underlying conceptual structures of the participants.

For the first phase of the observational astronomy interviews, children were asked a series of questions relating to the shape of the earth and the interaction of the sun and the moon with the earth. The children were then asked to elaborate on and explain their answers. For the second phase of fieldwork for observational astronomy the children were asked to create models of the earth, the sun and the moon, using clay. The participants were then asked a series of questions attempting to find out what their reasoning was. The participants were then asked to demonstrate the relationships between the earth, the sun and the moon.

3.4 DATA COLLECTION AND PROCESSING

For both instances of fieldwork, data were recorded on video. These recordings were translated, where necessary, and then transcribed. The researchers who assisted in conducting, recording, transcribing and translating the interviews all had what Miles and Huberman (1994) refer to as 'markers' of good qualitative researchers-as-instrument which are 1) familiarity with the phenomenon being studied, 2) strong conceptual interest, 3) a multidisciplinary approach, as opposed to a narrow grounding or focus in a single discipline, and 4) good 'investigative' skills, including doggedness, the ability to "raw people out", and the ability to ward off premature closure. The fieldworkers who assisted with the first phase of interviews were senior students in the faculty of education and who were fluent in isiZulu and together agreed on a final consensual, version of the text. The fieldworker who conducted the second phase of interviews was a B.Ed. Honours student in the faculty of education and conducted research in the South Africa Research Chair (SARChI) in the Centre for Education Practice Research on the Soweto campus. He is fluent in isiZulu and familiar with the phenomenon being studied. His translations were back-translated to firm up the reliability of the process of data collection (Henning et al. 2018).

The involvement of translators in qualitative research presents unique challenges for ensuring the trustworthiness of the generated data. Temple and Young

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(2004) ask three pertinent questions about translation in qualitative research: 1) Does it matter whether the act of translation is identified? 2) Does it matter whether the identity of the translator and the researcher are the same? 3) How far into the analysis of the data should a researcher involve a translator? All three these questions are important issues to consider during the design of the study; to ensure that accurate data can be generated, attention to translation issues is crucial (Van de Vijver & Poortinga 2004; Henning et al. 2018). Not being a speaker of isiZulu myself, inhibited my interaction with the participants of the study. I decided that for the reliability (and the trustworthiness of the results) of the inquiry, the children would be best accommodated in their primary language, with ample opportunity to code-switch to English. To compensate for that I selected reliable and competent fieldworkers who are known for their research assistantships in the research centre. Ketso[3], who was the main fieldworker and who also assisted with translation, is currently a lecturer in education at the university and has had ample experience as a fieldworker in various studies at the university and at the Department of Basic Education (Kotze, Fleisch & Taylor 2018).

Temple and Young (2004) and Henning, Van Rensburg and Smit (2004) argue that one also has to consider the epistemological position of the researcher: On a spectrum, varying from researchers being seen as 'objective' instruments of research who want to reduce bias as much as possible, on the one end, and viewing researchers as interpretive and constructionist on the other, has implications for translation of data (Van der Vijver & Poortinga 2004; Herholdt 2017; Henning et al. 2018). The production of knowledge is, according to these and other social science scholars (Henning et al. 2004), influenced by the researcher's position within the social reality of the inquiry. This 'social reality' view acknowledges that the translator becomes part of the knowledge production activity. This has been evident in the study and was taken into account in the planning. Ketso would thus, ultimately, be more than a technical translator – he would be an instrument of linguistic representation and thus contribute to meaning in a pragmatical linguistic manner (Halliday 2004; Halliday & Matthiessen 2013). The knowledge that the translator contributed to the generation of data would not have been possible if he had been excluded from the study itself. An external translator, who did not have the social experience of being present in the data

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[3] Pseudonym

collection could have distorted the data by a decontextualised translator. The importance and role of the translator in social science research is adequately summarised by Simon (1997:137) as follows:

> The solutions to many of the translator's dilemmas are not to be found in dictionaries, but rather in an understanding of the way language is tied to local realities, to literary forms and to changing identities. Translators must constantly make decisions about the cultural meanings which language carries, and evaluate the degree to which the two different worlds they inhibit are 'the same'. These are not technical difficulties, they are not the domain of specialists in obscure or quaint vocabularies…. In fact the process of meaning transfer has less to do with finding the cultural inscription of a term than in reconstructing its value.

This view provided a guideline in selecting a suitable translator for my study; I needed an individual translator that would be able to represent the meaning expressed by the participants of the study in such a way that it could be back-translated and verified by the teachers of the children. The challenge of the view of the researcher being an 'objective' instrument of research is that, in an attempt to reduce bias, utterances are translated and transcribed literally, risking the loss of the value of the utterances. In reading such transcripts, readers produce their own understanding of the text, based on their own assumptions, feelings and values that inherently increase the bias, due to the absence of *contextual validity* of the translation. I argue that, utilising the services of a translator within the knowledge production process has been beneficial to this study, because he has knowledge of the content and the context of the study. His description of the participants' utterances can, arguably, be more usable than the 'accuracy' of the translation of the participants' utterances by an outsider who may not note the underlying cues.

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3.5 DATA ANALYSIS TECHNIQUES

During the process of analysing the data, I first read through the (translated) transcriptions, while viewing the video at the same time. Each response of the participants was marked as an entity or a 'unit of meaning' for analysis purposes. Much of the initial coding was inductive (Strauss 1987; Strauss & Corbin 1990) and reduced/compressed the data into coherent and manageable entities that could be further utilised. Codes were assigned to each utterance/response in this way. These codes served as labels or tags that assigned meaning to descriptive and inferential information (Miles & Huberman 1994; Henning et al. 2004; Merriam 2013). The codes referred to sections of data and were assigned to single words, phrases, sentences or whole paragraphs, depending on the unitary meaning. Each code was reviewed and then grouped with other codes that were conceptually close and so *categories* of meaning were created. This is typical grounded theory analysis as presented by Strauss and Corbin (1994). Coding, in this sense, allows for information to be categorised and differentiated while giving an indication of the frequency of each category. Keeping in mind that this work is interpretive, and that the systematic manner in which I tried to do it was not just classifying meaning, but also 'giving' meaning. Such qualitative data analysis, although systematic, remains interpretive. 'Empiricistic' qualitative data analysis is merely a process of classifying and ordering. I did not wish to do that. Henning (1995) views this type of 'easy coding' as naïve 'empiricistic qualitative research'.

The process of coding and categorising developed along the lines of the Henning et al. (2004:104 - 105) model of qualitative data content analysis. This model suggests that, in the open coding phase, "codes are literally made up as the researcher works though the data…. The process of making inductive meaning, which is highly interpretive, is then preceded by a more technical process" which is transcribing the data verbatim. In this study I missed this specific process and relied on the English version that was written by Ketso, with whom I discussed the process of coding as it progressed, checking what the original isiZulu version was where needed to reach consensus.. Nevertheless, I argue that it was the optimal option – especially since there were such rich isiZulu expressions, which, Ketso translated very adequately, according to the teachers in the foundation phase at the school, who 'audited' his translations. They attested to the 'member checking' as a reliability mechanism on behalf of the children, whom they know well (Birt et al. 2016).

3.6 RELIABILITY OF THE PROCESSES AND VALIDITY OF THE FINDINGS

One of the cardinal aims of this type of qualitative case study is to reflect reality as accurately as possible (Merriam 1998), even while inevitably interpreting it. To ensure that the research account does accurately reflect the reality of the investigated case is not a simple endeavour and Borsboom et al. (2004) advises that the researcher should attempt to account for all processes, findings and conclusions as precisely as possible, in order to instil trust in the findings of the research. Qualitative research is deemed ‘good’ or ‘trusted’ when the findings and conclusions are reliable, valid, dependable, reasonable, confirmable, credible, useful, compelling, significant, empowering, and legitimate (Merriam & Tisdell 2016; Guba & Lincoln 1985) and when the processes to arrive at findings are stipulated precisely. The challenge for qualitative researchers, who do not have the epistemological partner of statistics, is to find appropriate ‘measurements’ of these elements. The validity of a study is not an absolute state that cannot be improved on, once certain criteria are met, but rather, validity is a matter of degree that can be improved through the addition of multiple criteria of the previously mentioned elements (Cohen et al. 2002). Borsboom et al. (2004) argues that the validity that is most pertinent for research is the validity of the findings in relation to the construct it reports on. The question is, how can one trust the findings and conclusions of a study if it is not possible to trace the steps in a type of ‘audit trail’? The validity of the study relies (thus requiring reliability), firstly, on its replicability and its evidential trail. Would another researcher, who follows the same design, who uses the same data collection protocols, and who studies similar participants, be able to draw similar conclusions from the findings of such a study (Merriam & Tisdell 2016)? Replicating qualitative studies is difficult, given the diverse perspectives of different researchers and their interpretations of the data. Merriam and Tisdell (2016) argue that it would be more beneficial to determine whether the results of the study are consistent with the data collected. The greater the *consistency and coherence of the results* with the collected and presented data, the greater the *dependability* of the findings. Eisenhart and Howe (1992) and Merriam (1995) agree that the coherence of argumentation as put forward in the study encourages debate and interrogation of research processes and results and, therefore, increases the trustworthiness of inferences, interpretations and conclusions drawn from the data.

Howe and Eisenhart (1990) propose five shared standards in qualitative research that would improve its overall validity/trustworthiness. These standards prove useful in the construction of firm arguments in educational research and present opportunities within each standard to choose design specific standards that would support the arguments made in the study: 1) The first standard proposes a *fit* between research questions, data collection procedures and analysis of the data in so far as the data collection and analysis is driven by the research question. 2) The second standard examines the credible application of data collection and analysis techniques. 3) The third standard raises questions about the researcher's alertness to his assumptions about existing knowledge and his awareness that his own subjectivity should be made explicit. 4) Standard four relates to the application of general principles to judge the arguments made in the study. 5) The fifth standard pertains to the comprehensive worth of the findings and conclusions of the study in informing and improving education. The last standard is pragmatic in the sense that different contexts require different senses of worthiness.

The overall validity of a study will ultimately be judged by its evidence about the object of the study as proposed and set out by the research question, the aims and the objectives of the study. There would need to be alignment between the inferences drawn from the findings, the empirical data and how these two elements intersect with the theoretical framework of the study. For this study I was guided by Miles and Huberman (1994), Henning et al. (2004), Saldana (2015), and Silverman (2013) in the various steps of research and analysis of data in qualitative research and I argue for both *construct* and *contextual* validity of the study. The construct of this study is children's conceptual development and conceptual change (theories and theory change), pertaining to their theorising of observable astronomy and vitalist biology. The reliability of the study would become evident when studying the audit trail as presented throughout this document. Ultimately, I would argue, that if the study can be regarded as reliable in its methods, and the construct and context is valid, that the findings of the study can be regarded as valid.

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3.7 ETHICAL CONSIDERATIONS

Miles and Huberman (1994) argue that to approach qualitative research with the aim of 'uncovering' truth at all costs is not practical because considerations about the moral and ethical treatment of research participants, peers and funders of the research should be on the foreground of the design of a study as to avoid the exploitation of the people whose lives are being studied. Determining whether a study is ethical remains a challenge to qualitative researchers, given the myriad epistemologies of ethics. For this study, I was guided by a set of principles as explained by Sieber (1992) and Marshall and Rossmann (2014) to ensure that ethics underpinned the design and execution of the study. The principles of beneficence, mutual respect, justice, noncoercion, and support for democratic values and institutions were incorporated throughout the design of the study and the execution of the research in the following ways.

This research was conducted in accordance with the education faculty's ethical standards and has been approved by the same faculty's ethics committee (See Appendix A) with clearance certificate number 2016-009. Approval was granted to conduct research in the school due to the agreement set out between both institutions that locates the school as research site for the department of childhood education. A formal letter was sent to the parents of the selected participants to explain the research and to obtain informed consent of participation. Participation in this study was voluntary and participants could withdraw from the study at any time. Anonymity, confidentiality, and privacy was maintained by not mentioning any names or specific identifying markers during the transcription and translation of the interview recordings. In respect of video recordings I have elected to only share these recordings with the translator, supervisors and assessors of this study to limit the exposure of the participants. The video recordings are stored on a mobile hard drive that is kept in safe keeping with only myself having access to the drive. Some videos were uploaded to a cloud based server, in this case, Google drive (see Appendix D) that ensures that only people who have been sent the link to these videos would be able to view the videos. This was done to ensure that assessors and supervisors could securely access the large files with ease instead of sending hardware that contained files that could compromise the identity of the participants if accessed by non-intended recipients. The risk to participants in this research were minimal, however, all participants were informed of the possible risks and ensured that all reasonable measures to mitigate these risks were undertaken by the researcher.

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3.8 ACTIVITY SYSTEM ANALYSIS (ASA)

For this study I used an epistemological 'grand theory' (Le Compte & Preissle 1993). According to these authors such a theory 'governs. The positioning of the researcher. In this study I deliberately positioned my thinking in what the philosopher Denis Phillips (Phillips 2000) and others refer to as a 'social constructivist' position. A social constructivist epistemology (Phillips 2000) regards individuals as being interconnected with society and with each other and is mediated through the semiotics via tools and via signs, such as language (Vygotsky 1978). In a study such as this thesis, the interactions and relationships between the child, the teacher and the environment wherein these interactions occur are be studied in order to identify the tensions that inhibit the proper development of the child's early theories. I have chosen to use third generation cultural-, historical-, and activity theory (CHAT) as systemic lens through which I *gaze* (Wardekker 2008) onto the data as knowledge. In doing this I see 'data interactions' and thus employ activity system analysis (ASA) as a heuristic, which Engeström (1987, 1991, 2001, 2015) introduced in the third iteration of the original activity theory of Vygotsky (1934/1978) and Leontiev (1979). Vygotsky (1978) proposed the term 'activity' to describe the intricacies of human interaction, both interpersonal interactions as well as the interactions with the sociocultural environment. The well-known metaphorical activity of the 'primeval hunt' has often been referred to in the early theorising of human activity in Soviet psychology of the first quarter of the 20th century (Leontiev 1979). In this metaphor there are several sets of integrated actions and tool-use performed by the members participating in the hunt. These actions include the stalking of the target animal as well as operations with a shared motive and objective. The hunt is motivated both naturally, driven by the need to obtain food, and culturally, mediated through the systematic use of tools and signs. This view of activity is known as first generation activity theory.

Cultural-historical theory was initially devised by Vygotsky and subsequently modified by two generations of Soviet and Scandinavian scholars, (www.iscar.org) after which it became applied widely in the social sciences. This lens is used to identify the 'tensions' within an *activity system*. Vygotsky (1978) was a proponent of what later became known as 'social constructivism' and posited that children 'make use' of society to assist them in communicating and to make meaning of their reality. He proposed that learning occurs on two levels: the first on a social level by interacting with others; and the second on a personal level where the socially constructed knowledge is internalised. This would allow them to develop individual cognition (Rogoff 1990). Language serves as a semiotic device that mediates the meaning making process and is seen as "perhaps the most formal of human meaning systems" that a society can share (Odora-Hoppers 2005:1). The young child entering formal schooling therefore has five years of language and conceptual developmental history. CHAT is used in this study as a lens to peer through the window of concepts and theories of children who have grown up in Soweto and have entered the school where the research was conducted.

Engeström's (2001) third generation activity theory comprises six factors which should be considered within each 'activity system' such as a classroom or the learning activity of an individual child. All these factors are dynamically interconnected either directly or indirectly, which results in an outcome (Hardman 2008). The dynamic nature of the interactions between these factors will inevitably have an impact on the other factors and on the envisaged outcome. This constitutes an activity system which can be illustrated as follows:

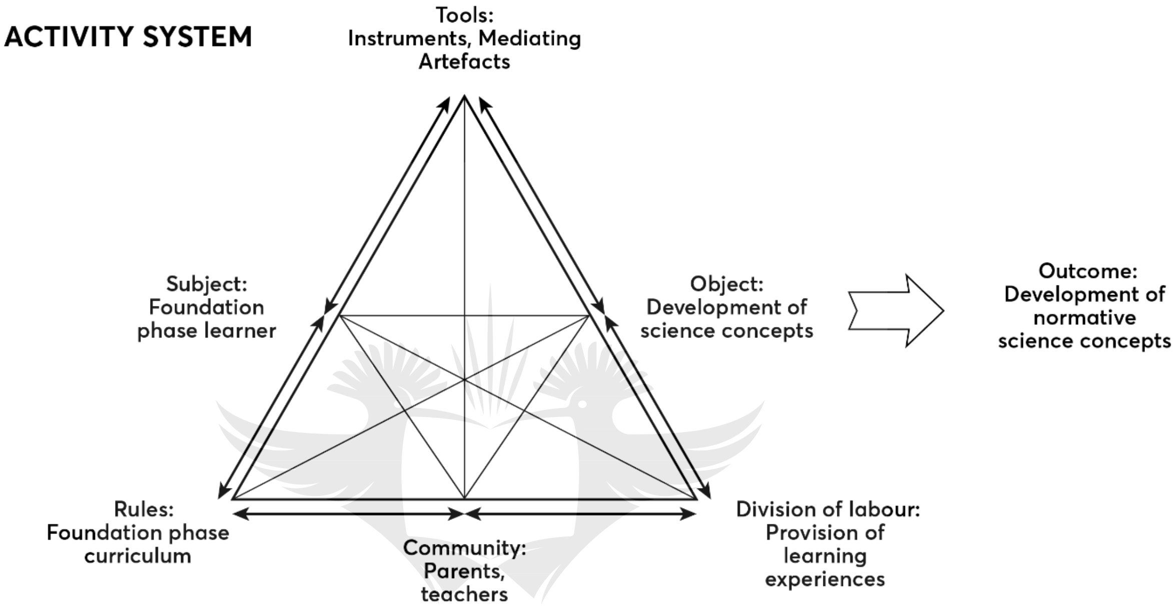

Figure 3.3: The bounded activity system of the case study

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Engeström (1987) developed the third generation activity theory by elaborating on the models proposed by Vygotsky and Leontiev in the first two 'generations' of this theory.

An activity system is useful in the study of human interaction and behaviour as it becomes the basic unit for research of these interactions. Roth and Lee (2007) posit that the people within an activity system constantly and dynamically shape each other, hence the two-way arrows in the diagram, during their interactions. The top tier of the triangle still resembles that of first generation activity theory with the tools that mediate the activity placed at the apex. The base of the triangle now includes the individual action that occur not only towards the object, but which includes the social realm.

Third generation CHAT was used as analytical framework for this study in which the development of science concepts of foundation phase learners was analysed. CHAT is appropriate for this study as it allows one to view the child within a whole context taking his historical and cultural background into consideration.

For the purposes of this study the different factors as depicted in Figure 3.3 will be interpreted as having the following meaning:

The envisaged outcome is that the foundation phase learners adequately develop normative science concepts that would form the foundation for future science learning. Given that social constructivism suggests that learning of these concepts occur in a social setting but depends on the personal internalising of the concepts, the subject of this activity system is the foundation phase learner who uses tools such as language, to communicate within the social setting of the activity system. These tools influence the object which is the development of the science concepts. This is achieved within the rules of the activity system which in this case is bounded by the rules of the foundation phase curriculum as well as those of the community wherein the child grew up. The community in this case consists of the parents, teachers and other significant individuals that could influence the development of the child's concepts of the natural world throughout the development of the child. The division of labour within this activity system contributes to the achievement of the outcome seeing that the role of the teacher and parents are to present the learner with experiences that would allow the child to form and develop concepts. The role of the child is to actively participate in the meaning making whether it is explanatory or exploratory in nature.

The argumentative base for the design of this study, namely that for the optimal development of science concepts, children have to be exposed to learning opportunities that allows them to restructure their conceptual networks. I argue that this could be achieved within an activity system that values and comprehends the nuances of conceptual development.

3.9 CONCLUSION

The design of this study has certain strengths: it can claim contextual validity (Golafshani 2003, Borsboom & Mellenbergh 2004), because the young learners were investigated in their everyday environment, with the aim of creating specific knowledge for the teacher education programme. For the learners, the sharing of their everyday school life was not an invasion of their privacy in any way. The Achilles Heel of the study was the process of translation and the extra measures that had to be taken to verify the translation.

As a case study, the inquiry has had a strong bounded system to investigate and the unit of analysis has remained at the core of the inquiry. In the data analysis chapter, which follows, this statement is put to the test. The strong reliance on the framework of conceptual change has served the design well, while the ASA served to examine the phenomenon in the real world of the system in which the child participants live and learn.

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CHAPTER 4

THE DATA OF THE STUDY

4.1 INTRODUCTION

This chapter sets out the process of collection and analysis of the data – culminating in the main themes. In the case study of a group of young learners these themes were constructed from the analysis in two phases of inductive coding and then collapsing the codes to form categories (Henning et al. 2004; Merriam 2016; Strauss & Corbin 1990). The data were generated on two separate iterations, in classroom group interviews during a 'science demonstration', and in task-based (clinical) interviews, the aim of which was to capture the learners' expression of their conceptions of two topics in the curriculum, namely observational astronomy and vitalist biology. The results from the data analysis is presented as four different data sets. In Chapter 5 I will show the coherence between these themes and how they together constitute the main finding of this study. Section 3.5 explains the design reasoning of the interview protocols used during the different iterations of the fieldwork.

This chapter comprises the representation of the data as codes and categories for the classroom group interviews (see 4.2) and then a separate section for the codes and categories for the task-based interviews (see 4.3). The chapter concludes with the listing of the final themes and patterns that are evident from the analysis of the data.

4.2 SCIENCE DEMONSTRATION CLASSROOM INTERVIEW DATA

In the following section I show the codes and categories as generated from the science demonstration classroom interviews. For the purposes of this section I will show the conceptual collapsing of codes into categories and discuss the reasoning (by way of examples) for the creation of these categories. The categories are labelled with a distinct code, showing the data set whence these categories come.

These demonstrations took place during classroom demonstration in one Grade R and one Grade 3 classroom. I illustrate the coding process by using an example of how a category, in this case Category SSR2[4], was generated from the raw data as can be seen in the transcription of the Grade R classroom interview (Appendix B).

Interviewer:	Can you tell me what the sun does?
Participant 1:	It is hot.
Participant 2:	When our clothes are wet it makes them dry.
Participant 3:	And shoes.
Participant 4:	When you have a sack and it is wet the sun comes and makes it dry.
Participant 5:	When our clothes are dry we put them in the wardrobe.

The first step was to codify such utterances, resulting in the following primary code (raw code) 'the sun dries wet clothes'. This code, along with two others, as generated from other utterances, 'the sun gives light to see' and 'the sun gives heat so we can play', were collapsed into a secondary code named 'the sun is a functional agent that facilitates human activity'. This secondary code was grouped with two other codes, 'the moon is a functional agent that facilitates human activity' and 'shadows are given human only traits' to generate Category SSR2 'Celestial bodies are personified'. In Section 4.4 I collapse all similar categories into the themes that were abstracted during analysis.

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[4] The category acronyms were chosen to maintain an audit trail of the data sets in order to avoid confusion due to the multiple data sets. As an example, Category SSR2 refers to the **S**cience **S**how that was conducted in the Grade **R** classroom. The number '2' refers to the second category in the series.

4.2.1 Grade R

Primary- and secondary codes, and categories, as generated from the translations of the Grade R science demonstration classroom interviews on observational astronomy were captured from transcriptions.

Table 4.1: Results of data analysis of Grade R classroom interviews on observational astronomy

Primary Code	Secondary Code	Category
Expressive language is a limitation	Influence of Language on Learning in Science	**SSR1.** Limited expressive vocabulary inhibits explanations
Sun gives Light to See Sun gives heat so we can play Sun dries wet clothes	Sun is a functional agent that facilitates human activity	**SSR2.** Celestial bodies are personified
Moon shows you it is time to sleep	Moon is a functional agent that facilitates human activity	
Shadow is a human No shadow at night because of cold	Shadow is given human only traits	
Sun position is up Moon position is up Stars' position is up	'Up' is the position of celestial bodies	**SSR3.** Description and explanation of phenomena is naïve
The sun goes home at night Stars go to the sky during the day	Celestial bodies don't move in an orbit	
Children relate phenomena to their personal experience Night time is when the thieves come	Children relate natural phenomena to their own experience	**SSR4.** Children relate phenomena to social reality

The moon is a banana	Shape of celestial bodies are described as fruit shapes	**SSR5.** Objects are classified and described as geometrical shapes

Category SSR1. Limited expressive vocabulary inhibits explanations

During the science demonstrations it became evident that learners struggled with expression (through the medium of) the vocabulary of science. The initial question of the interview asked the class to describe what science is. Some participants, after giving a pause, answered by giving similar sounding words such as “sun” and “stop sign”. It became evident that expressive language is a limitation and may even have caused much confusion. However, the participants started to comprehend what was asked of them only after the translation of the question into isiZulu, with some explanation in isiZulu.

Category SSR2. Celestial bodies are personified

Throughout the series of questions on observational astronomy learners often assigned human characteristics to various celestial bodies such as the sun and the moon. Three secondary codes make up this category. Each one will be discussed separately.

The sun is a functional agent that facilitates human activity

For some of the participants the sun acted as an agent that provides opportunity for them to perform activities. Participants would answer the question on the function of the sun as “the thing that lights for us to see”; “the sun makes it to be warm when it is cold so that we can go to the street and play while it is hot”; and “when our clothes are wet it makes them dry”. These answers showed that the participants had good understanding of the characteristics of the sun in that it provides light and heat. What is particularly interesting is the addition of a qualifying effect of the characteristics in that it facilitates human activity and that the understanding is personalised and ‘egocentric.’ Overall I had the sense that it is almost as if the sun becomes the facilitator (or even catalyst) of human activity and that we would not be able to conduct these activities if the sun didn’t ‘decide’ to provide us with light or heat. The sun was also featured as a ‘decision-maker’.

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The moon is a functional agent that facilitates human activity

The function of the moon was stated as "it shows you it is night" and "it shows you that it is time to sleep". In much the same way as with the questions about the sun, the participants represented the moon as an agent that allows humans to do certain activities by 'showing' us the time. The personification is not entirely evident within the transcribed text of the interviews but lies within the tone of voice of the participants.

Shadows are given human traits

When asked to describe what a shadow is the participants initially used the term "shade" to describe what a shadow is, once again showing the facilitation of human action in the way that shade gives relief from the sun. The participants then described the shadow by answering that it was "a human" that does not appear "…at night because of the cold" and because "the thieves come" at night, thus personifying the notion of shade to only being the shadow of a human. They attributed human characteristics to a lifeless figure that resembled the familiar shape of a human. The causal reasoning that underlies these answers is logical, but the normative science concepts remain elusive.

These responses show that the participants assigned human-like characteristics or relationships to various phenomena.

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Category SSR3. Description and explanation of phenomena is naïve

Throughout the interview there were clear indications of naïve conceptual expressions. In this instance I identified two categories of naïve concepts relating to observational astronomy.

'Up' is the position of celestial bodies

When asked to indicate where the sun or the moon is situated, most participants raised their hands pointing upwards and said that these celestial bodies were "up". Most of these interviews were conducted during the morning yet the moon was still indicated as being in the apex of the sky. None of the participants gave an alternative response to having the sun and the moon in the same position in the sky. For the participants, the moon is the guide at night and the sun gives heat and light in the day. That is how far their reasoning extends. When asked if the moon was visible during the day the participants unanimously said “no” even when at the time of the interview the moon was indeed visible in the morning sky through the classroom window.

Celestial bodies don’t move in an orbit

The participants were asked what happens to the moon during the day and what happens to the sun at night. The majority of responses did not indicate any understanding of the orbital movements of these celestial bodies. Instead, the participants had either a linear view of the movement of the sun and the moon in that it moves away from the earth, or an abstract concept of where these celestial bodies go. One participant mentioned that the sun goes “home” at night. When asked where ‘home’ is, the participant could not answer the question. Another participant indicated that the sun “goes to the sky” during the day, showing her understanding of linear movement of the sun away from the earth instead of orbiting around it.

Category SSR4. Children relate phenomena to social reality

The most evident example of this category relates back to the answer of one of the participants on the question about shadows. The dangers that these children experience on a daily basis is part of the explanation of why the shadow is not visible at night. It isn’t visible because “the thieves come.” Furthermore, when explaining the function of the sun and that of the moon the participants answered from their unique perspective i.e. the sun provides heat in order for *them* to play and light so that *they* can see. The explanations are not separated from their own experiences.

Category SSR5. Objects are classified and described as geometrical shapes

There was a high prevalence of instances where participants used geometrical terminology to describe the celestial bodies throughout all of the data sets. In this particular interview the participants described the shape of the moon as shaped like a banana. In fact, the moon was described as actually being “a banana”. This also showed the use of a metaphor of a known object because the specific concept or terminology of the shape ‘crescent’ is not known to the participants.

The following section shows the codes and categories as generated from the Grade R science demonstration classroom interviews on ‘vitalist biology’.

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Table 4.2: Results of data analysis of Grade R classroom interviews on vitalist biology

Primary Code	Secondary Code	Category
Breathing as vitalist discourse	Respiration as vitalist discourse	
Walking as vitalist discourse Water is alive because it shakes Not walking discourse of not alive Walking as vitalist discourse Flying as vitalist discourse Standing as vitalist discourse 'Go' as vitalist discourse	Movement as vitalist discourse	
Drinking water as vitalist discourse Flowers are alive because it needs water	Ingestion as vitalist discourse	**SSR6.** Vitalist discourse relates to obvious observable characteristics and is naïve and 'egocentric' (or anthropomorphic)
Seeds come from fruit	Growth as vitalist discourse	
Trees don't talk = not alive Talking as vitalist discourse	Communication as vitalist discourse	
'Go' as vitalist discourse	Excretion as vitalist discourse	
Rock is different from dog because dog has teeth.	Presence of teeth is important for vitalist categorisation	

Use colours to categorise birds	Categorisation: Based on colour	**SSR7.** Classification / categorise according to colour
Trees are for hiding	Children relate phenomena to their personal experience only	**SSR8.** Children relate phenomena to their own experience

Category SSR6. Vitalist discourse relates to obvious observable characteristics and is naïve and 'egocentric' (or anthropomorphic)

During this interview it was possible to identify which characteristics of an object these participants deemed important to classify the object as living or non-living. Seven categories arose that displayed the views of the participants.

Respiration as vitalist discourse

Throughout this interview participants were asked whether the different objects were alive or not and only in one instance did a participant consider breathing as a reason for the object, in this case a human, to be alive. Breathing falls in a subcategory of vitalist categorisation as respiration would have been a more accurate characteristic of living organisms.

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Movement as vitalist discourse

The responses during this interview favoured movement as a characteristic of living organisms. Being able to walk, shake or fly was pertinent considerations for the participants. For some of the participants water was classified as living on the basis that it moves. Certain participants asked as a rebuttal to the claim that water was not alive that "why does it shake then?" In another instance a seed was seen as non-living because "it does not walk."

Ingestion as vitalist discourse

Being able to drink or eat was also a consideration for the characteristics of living organisms. One participant mentioned that humans were alive because "you drink water." However this was the only reference to ingestion in the entire interview.

Growth as vitalist discourse

In this interview there was one instance where growth was related to the characteristics of living organisms. When asked whether a flower is alive the majority of the class agreed that it was alive. Their explanation was “because it needs water.” After further probing, the participant mentioned that the water is needed for the flower “to grow” and an object that grows is alive. This could also be connected to ingestion as vitalist discourse but I do not believe that this was the direct intension of the participant.

Communication as vitalist discourse

Trees were considered to be non-living “because it is not talking” whereas the dog is alive “because it’s talking.” One of the participants imitated the sound of a dog “whoof-whoof!”

Excretion as vitalist discourse

Throughout all data sets there was only this one possible conspicuous mention connected to excretion as consideration for the characteristics of living organisms. When asked whether the dog was alive, one participant said that the dog was alive “because it go.” The language here is problematic as it is unclear whether the participant intended that ‘go’ referred to the action of ‘go’ing to the toilet or whether it referred to ‘go’ as in ‘move’. From the recording I lean more toward the notion that the participant intended excretion rather than movement.

Presence of teeth is important for vitalist categorisation

When asked what the difference was between the dog and the rock, one of the participants mentioned “because the rock doesn’t have teeth” and showed that an object needed to have similar features or organs as humans to be considered to be alive.

Category SSR7. Classification / categorise according to colour

During the section of the interview where a real bird was presented to the class I asked the participants what other birds they know of. Instead of providing names of different breeds or species the participants mentioned an array of different colours.

Category SSR8. Children relate phenomena to their personal experience only

The example for this category comes from the answer of a participant on the question asking "what other trees do you know of?" In this case the participants did not list trees by colour but it was clear that they answered in relation to their experience and interaction with trees. The most pertinent example of this comes from the answer "the ones for hiding." This answer could stem from the participant using a tree to hide away when playing games.

4.2.2 Grade 3

The Grade 3 science demonstration classroom interviews yielded an array of codes and categories on observational astronomy. These categories are discussed in this section.

Table 4.3: Results of data analysis of Grade 3 classroom interviews on observational astronomy

Primary Code	Secondary Code	Category
Science is magic	It is difficult to explain what science is	**SS31.** Limited vocabulary inhibits explanations
Language limitations ('planets' vs 'plants')	Evidence of vocabulary confusion	
Moon is sometimes whole	Evidence of suitable vocabulary and some conceptualisation	
Light tells you it is morning	Sun is an agent that facilitates human activity	**SS32.** Description and explanation of phenomena is naïve
Sun is fire Sun is bright like a star	Analogies used to describe the sun	
Sun's position is up	Description of the position of the sun is naïve	

Sun is in the sky		
Sun is in Space Planets are in Space	Description of the position of the sun is celestial	
Moon is a planet	Moon is a planet	
Sun goes up to the sky at night Sun goes under the moon at night Clouds close the sun at night	Description of the sun at night is naïve	
The sun hides at night	Sun is personified	**SS33.** Celestial bodies are personified
Moon comes out at night	Moon is personified	
Moon is banana shaped	Moon is described using shapes of everyday objects.	**SS34.** Objects are classified and described using geometrical shapes
Moon is a circle	Moon is described using geometrical shapes	
Classify sun and star on shape	Classification based on shape	
Stars are rectangles	Stars are described using geometrical shapes	
Moon becomes half during the day	Changing nature of the moon is noted	**SS35.** Changes in phenomena are observed and noted
Classify sun and stars on colour	Classification based on colour	**SS36.** Objects are classified and described using size and colour

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Classify sun and star on size	Classification based on size	

Category SS31. Limited vocabulary inhibits explanations

This category surfaces in each one of the data sets and I will provide the evidence for each data set separately. In this case the data were organised in three categories.

It is difficult to explain what science is.

At the start of the interview the participants were asked to explain what science is. In this Grade 3 classroom none of the participants could give any definition or explanation. Only after being prompted did one girl answer that science was magic.

Evidence of vocabulary confusion.

During one segment of the interview the participants were asked to show where the sun was. One response was that the sun was "in out of space" which is a misnomer for 'outer space' but when asked what 'space' was the participant answered that it was "a planet". The follow up question asked the participants to describe where planets were and he answered that the planets are in the garden, referring to plants instead of planets. This shows some confusion between terminologies that sound similar.

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Evidence of suitable vocabulary and more normative conceptualisation

As opposed to the Grade R interview, here we saw some evidence of discourse that is less naïve and closer to an accurate description of phenomena. During the Grade R interview the participants referred to the shape of the moon as a banana indicating the crescent shape of the moon. During the Grade 3 interview the participants referred to the "half-moon" as well as that the moon "sometimes it's whole." However, there were still responses from some of the Grade 3 participants that the shape of the moon "is like a banana".

Category SS32. Description and explanation of phenomena is naïve

There were multiple instances during this interview where the participants exhibited their naïve expressions of phenomena. These have been categorised in 6 categories.

The sun is a functional agent that facilitates human activity

As with the Grade R interview, we still saw this category repeated with the Grade 3 participants. In their explanation there was a perceived agency from the sun in that it facilitates human action. In asking how they knew that it was morning one participant responded that "you see with light" and another answering that "I see outside, when it is white outside" followed by another participant adding "and the sun." Collectively the responses show that they think the sun provides the light that allows them to see when the environment is lit.

Analogies used to describe the sun

Throughout the interview some of the participants used analogies when trying to describe and explain phenomena. The sun in particular was described as being "fire" and when asked to describe what fire is, another participant responded by saying fire is "light". Even though these analogies aren't incorrect it was clear that the participants did not have a nuanced understanding of the difference between the heat and light energy provided by the sun. This however, shows greater conceptual understanding of the function of the sun as compared to that of the Grade R class.

Another analogy that was used was uttered during an exchange between the participants when asked whether the sun was a star. In this instance one participant agreed that the sun is a star "because it is bright like a star." The remainder of the class did not believe that the sun was a star and described differences in colour, size and shape of the two seemingly different concepts.

Description of the position of the sun is naïve

As with the Grade R class the position of the sun was "up" and "in the sky." When asked to explain what happens to the sun during night time the participants responded by saying that the sun "goes up in the sky" in much the same linear movement as described by the Grade R participants. Others explained that "it go under the moon" while others explained that "the clouds close the sun." One participant said that "the

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sun hides and it becomes dark." During this exchange we saw greater diversity in explanations as compared to that of the Grade R class.

Description of the position of the sun is celestial

The mention of 'outer space' during this interview is an addition that was not seen during the Grade R interview. Some of the participants had a more normative concept of the sun as a celestial body situated in space. There were also spontaneous mention of planets that are in space. However their understanding of the interaction between the earth, the sun and the moon was still naïve.

Moon is a planet

The interviewer asked the participants where planets are, during the exchange where a participant confused the terminology of 'planets' and 'plants'. One of the responses from a participant showed a common inaccuracy that the moon is a planet.

Category SS33. Celestial bodies are personified

Both the sun and the moon were given human-like characteristics by some of the participants. In response to the question on what happens to the sun at night, one participant explained that "the sun hides and it becomes dark". The act of hiding here being the personified characteristic. The moon was given human-like characteristics like "it comes out" at night also implying that it was hiding.

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Category SS34. Objects are classified and described using geometrical shapes.

There was a high prevalence of descriptions where shapes related to geometry was used to describe and classify objects. Four examples of this was evident in this interview. As explained earlier the moon is described as being banana-shaped referring to the crescent shape of the moon. The moon was also described as being "a circle" or a "half-moon." When describing the differences between the sun and stars some participants mentioned a difference in shape where "the sun is a circle" and "the star is a rectangle."

Category SS35. Changes in phenomena are observed and noted.

The participants in this interview showed that they noticed and observed changes in phenomena. Even though these relationships were explained using naïve concepts it was evident that they realised the relationship between various phenomena. The example from this data set relates to the phases of the moon. These participants were aware that the moon's shape changed as opposed to the Grade R interview where all participants noted the crescent shape of the moon. There was mention made that the moon "gets circle when it is morning" indicating the awareness of a change in shape by using the word "gets". Another participant said "sometimes it [the moon] is whole" implying that they are aware that at other times the moon is not whole. When asked what happens to the moon during the day one participant responded that "it becomes half."

Category SS36. Objects are classified and described using size and colour as criteria.

Several instances where objects were classified based on their size or their colour were captured during this interview. The moon was described as being white and the sky as being blue. When comparing the sun and stars a distinction was made based on colour as a "star is white and sun is yellow." The difference between these two objects were explained using size as characteristic. One participant stated that "the sun is big and the star is small".

Codes and categories as generated from the Grade 3 science demonstration classroom interviews on 'vitalist biology'.

Table 4.4: Results of data analysis of Grade 3 classroom interviews on vitalist biology

Primary Code	Secondary Code	Category
Speaking as vitalist discourse Can't speak with water Can't speak to water	Communication as vitalist discourse	**SS37.** Vitalist discourse relates to obvious observable characteristics and has progressed but is still not normative and closely related to human life
Walking as vitalist discourse Running as vitalist discourse	Movement as vitalist discourse	

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Trees move because of wind (Tree is alive)		
Breathing as vitalist discourse Water can breathe	Respiration as vitalist discourse	
Eating as vitalist discourse Drinking as vitalist discourse	Ingestion as vitalist discourse	
Touching as vitalist discourse Can't touch air	Touch as vitalist discourse	
Washing as vitalist discourse	Cleansing as vitalist discourse	
Sitting as vitalist discourse Driving as vitalist discourse Exercise as vitalist discourse Kicking as vitalist discourse Stretching as vitalist discourse Water does not have hands Water does not have mouth Water does not have a face Water does not have legs	Relationship to human activities and human features relate to vitalist characteristics	
Growth is not a characteristic of life	Growth is not a characteristic of life	
Flowers can't listen	Hearing as vitalist biology	
Reproduction as vitalist discourse	Reproduction as vitalist discourse	

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Flowers are not alive Trees are not alive	Plants are non-living	**SS38.** Plants are generally considered as non-living
Nothing in balloon when inflated.	Air is not seen as matter	**SS39.** Theory of matter is naïve
Seeds are beads of flowers	Relation to cultural artefacts	**SS310.** Sociocultural component of natural objects
Give flowers to friends for birthday Flowers to decorate your house	Flowers have a social interpersonal role	
Flowers make fruit when given water	Relationship between flowers and fruit are evident	**SS311.** Learners note relationships between natural phenomena
Trees move because of wind (Tree is alive)	Influence of wind on movement is evident	
Dogs categorised according to names	Categorisation based on names	**SS312.** Objects that are familiar are classified and described using terminology

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Category SS37. Vitalist discourse relates to obvious observable characteristics and has progressed but is still not normative and closely related to human life

After analysing the responses of the participants for this section of the interview I have seen evidence of vitalist discourse that is similar to that found in the Grade R interview. It is clear that the expression of concepts had progressed but was still not normative. I have collapsed the codes into ten categories which will now be discussed separately.

Communication as vitalist discourse

Being able to talk was a pertinent consideration for some of the participants to classify an object as being alive. When asked whether they were alive and to provide reasons for their answer one girl explained that she was alive because “we can speak” with another girl adding that “we can speak a lot.” Rocks, seeds and flowers were deemed to be non-living because “it can’t talk” and birds were alive because “it can sing.”

Movement as vitalist discourse

Movement was considered as a characteristic of living organisms. Humans were alive because “we can walk” and “we can run.” Water however was deemed not to be alive because “the water can’t walk.” Not being able to walk ensured that some participants classified flowers as non-living. One girl responded contrary to the rest of the participants when asked whether a tree were alive. She said that a tree was alive “because the tree can move” and explained that the tree moves “when there is windy”. Another boy added that trees move “when the air is more.” The bird was deemed alive because “it can fly” and the dog was alive because “it can run.”

Breathing as vitalist discourse

In this interview the participants considered breathing as an important factor in classifying objects as living or non-living entities. Humans, birds, dogs and even water was considered being alive because they breathe. Seeds and flowers are considered non-living because they do not breathe.

Ingestion as vitalist discourse

Ingestion of food was a consideration for the participants, in this interview, to classify objects as being alive. Humans, birds and dogs were considered alive because “it can eat” and “it can drink” whereas seeds and flowers were deemed non-living because “it can’t eat” and “it can’t drink water.”

Touch as vitalist discourse

The participants classified, on a few occasions, objects as living based on the fact that the object was able to touch another object. Humans were alive because “we can touch.” Air was interestingly classified as non-living because “you can’t touch it” and “you can’t hold it” or even “you can’t hug it.”

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Cleansing as vitalist discourse

On a few instances the participants referred to the ability of an object to clean itself as a characteristic of a living organism. When asked whether a rock was alive or not one girl responded by saying that the rock was non-living because “it can’t bath.”

Relationship to human activities and human features relate to vitalist characteristics.

In many cases the consideration of the participants were related to actions that they commonly associate with the actions of humans. Some of these instances have already been used as example in the previous categories. Here I will show the instances that were not included in the other secondary codes of this category. Humans were classified as living because “we can drive” a car, “exercise”, “kick”, “stretch”, “smile”, “sleep” and “tie your shoe.” Air was deemed non-living because “you can’t hug it.” The activity of building was mentioned on two occasions. The rock was considered to be non-living because “you can’t build with it” whereas the bird was considered living because “he can make his own house.”

Interestingly, not only human activities but also bodily features, especially anatomy, also were a consideration in classifying an object as living or non-living. Water was non-living because it “don’t have bones”, “doesn’t have legs”, “no hands”, “doesn’t have a face” and “don’t have a mouth.” A tree was deemed non-living “because it don’t have feet”. The bird was considered alive because “it has a heart” and “it has eyes”. The dog is alive because “it has bones”, and “it has teeth and [a] mouth.”

Growth is not a characteristic of life

The participants referred to growth on multiple occasions during the interview but did not consider it as a characteristic of living organisms. A series of questions asked the participants whether a seed was alive. The general response was that it was non-living even though it grows. When asked whether humans grow and if they are alive the participants affirmed that humans do indeed grow and is living. The causal link between growth and being alive was not made. This happened on two occasions. During the series of questions pertaining on the seed as well as the series of questions on the pot plant.

Hearing as vitalist biology

Being spoken to and being able to hear were considered to be characteristics of living organisms by some participants. For instance, water, air, and the rock were deemed non-living because "you can't speak with it." The tree was considered non-living because "… the tree can't listen."

Reproduction as vitalist discourse

On only one occasion during the interview did a participant refer to the ability to reproduce as a characteristic of living organisms. When asked whether a dog was alive, one participant agreed that the dog is living because "it can make babies."

Category SS38. Plants are generally considered as non-living

On most occasions all plant matter were considered as non-living. This was evident from the responses of the participants who cited lack of movement, not breathing, does not exhibit human-like traits, and not eating or drinking, as reasons why plant matter is deemed non-living.

The only two instances where participants deemed plant matter as living was from the responses of one boy and one girl, respectively, who were asked whether the tree was alive. The boy responded that the tree was indeed alive "because it grows apples" and the girl responded: "I say yes because the tree can move." The girl was referring to the motion of the leaves in the wind.

Category SS39. Theory of matter is naïve

It was evident from many of the examples mentioned thus far that the conceptual understanding of many of the concepts were naïve or very poorly developed. One instance made this clear. When the participants were shown a deflated balloon and asked to describe what was in the balloon they answered that it contained "nothing." No one stated that the balloon contained some air. After inflating the balloon the question was repeated and all participants mentioned that the balloon now contains air. There was therefore no discrimination between the amounts of air in both these scenarios.

Category SS310. Sociocultural component of natural objects

From some of the responses I could gather that the participants' answers were influenced by instances from their cultural background. When asked what one can do with flowers the participants mentioned that "you can take them and then you give your friend" showing the cultural practice of gifting flowers for occasions like another's birthday or "because you love" your friend. Another participant referred to the aesthetic value of flowers by stating that "you can plant your flowers in your house" and "you can decorate inside your house."

The other example refers to the confusion between terminologies. When presented with sunflower seeds and asked to describe what it is, one participant said that it is "the beads of a flower." In this community the practice of beading to create traditional clothing is common place and probably influenced the confusion in terminology given that the sunflower seed could resemble one of the beads used in this practice.

Category SS311. Learners note some relationships between natural phenomena

Many participants spontaneously mentioned relationships between different objects or phenomena during their responses. It was evident that they knew the causal relationship between water, sunlight and plant growth. The explanation of their reasoning was, however, superficial in that they only know that water and sunlight is needed for growth but couldn't explain any form of mechanism that could cause the growth. When asked why flowers needed water, one participant answered that it was done "to make fruits." The participants were at no stage presented with a fruit during the interview and this participant used knowledge from her own experience to answer the question. Another example of the participants' knowledge of causal relationships was the exchange on why trees move mentioned earlier in this section.

Category SS312. Objects that are familiar are classified and described using terminology

When asked what type of dogs they had at home, the categorisation of these dogs where based on an attempt to remember the breed e.g. "Rodviders", "Pitbulls" and "China dog" or it was based on the pet names of the animals eg. "Snoopy", "Scratch" and "Smokey."

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4.3 CLINICAL INTERVIEW DATA

In the following section I show the codes and categories as generated from the individual task-based clinical interviews that were conducted with a 2017 cohort of Grade R learners as well as the Grade 3 cohort (who were in the Grade R 2014 cohort and took part in the science demonstrations and the interviews). The coding process employed to generate the categories for these data sets were done similarly to the process followed for the science demonstration classroom interviews. The only deviation is that the raw data were not transcribed verbatim, given the complexities of the interview protocol in that utterances coincided with visual data. I reasoned that it would be prudent to analyse the data and generate codes from viewing the interviews (Appendix E) and translated versions of the recordings (Appendix D) simultaneously.

4.3.1 Grade R

Codes and categories as generated from the Grade R individual clinical interviews on observational astronomy.

Table 4.5: Results of data analysis of Grade R individual interviews on observational astronomy

Primary Code (n = frequency)	Secondary Code	Category
It is like that / That is how it is (15)	Difficulty explaining reasoning (15)	**CIR1.** Limited vocabulary inhibits explanations (15)
Earth Shape is 2D (9) Earth is flat (6) Sun is 2D (5) Moon is 2D (4)	2 Dimensional view of celestial bodies (24)	**CIR2.** Conceptual expression is naïve (41)
Sun has rays (7)	Solar rays are made visible (7)	
Sun position is on top of / touching the earth (4)	Rectangular or disc earth synthetic model (4)	

Moon opposite side of sun (6)	Sun and Moon are antithetical (6)	
Earth is 3D (1) Sun is 3D (3) Moon is 3D (4)	3 Dimensional view of celestial bodies (8)	**CIR3.** Conceptual expression is somewhat normative (11)
Yellow shows temperature is hot (3)	Relationship between colour and characteristic (3)	
Earth is a circle (4) Earth is round (1) Sun is a circle (7) Rays are sticks / lines / Triangles (4)	Geometric description of the earth and Sun (16)	**CIR4.** Connections to other subjects, specifically geometry (35)
Moon is crescent (7)	Moon is crescent shaped (7)	
The sun is yellow (6) Moon is white (6)	Description of phenomenon is based on observable characteristics (12)	
I like to make it in this shape / colour (11)	Individuality as consideration for shape and colour (11)	**CIR5.** Strong sense of self (egocentric expression) (11)

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Category CIR1. Limited vocabulary inhibits explanations.

Throughout the interviews with the Grade R learners there were 15 instances where the learners could not explain their choices and decided to answer with “because that is how it is.” The participants could not find the explanatory fodder in their vocabulary to express the reasoning behind their choices. An example of such an instance comes from participant FFR1 where she chose to depict the earth as a flat rectangle. When asked why she chose to use that shape she responded: “It is like that.” Another instance is observed when participant FFR5 uses white clay as the colour of the earth.

When asked to explain her choice she said: “The earth is like this.” No further explanation was attempted.

Category CIR2. Conceptual expression is naïve.

There were 41 instances where the participants expressed their concept of a phenomenon in a naïve manner. This category was collapsed from the following four secondary codes.

Two-dimensional view of celestial bodies

More often than not the participants in these interviews depicted celestial bodies as two-dimensional structures. On 24 occasions they either depicted the earth, or the sun, or the moon as two-dimensional objects. The following figure shows some of these clay models:

Figure 4.1: Participant FFR1’s model of the earth.

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Figure 4.2: Participant FFR2’s model of the earth and sun

Figure 4.3: Participant FMR3's models of the earth, the sun, and the moon

Solar rays are made visible

There were seven instances where the participants made the solar rays visible. Figures 4.4 and 4.5 show examples of the clay models that the participants made.

Figure 4.4: Participant FFR3's model of the sun including the visualisation of the sun rays

Rectangular or disc earth synthetic model

For four of the participants the relationship between the three celestial bodies were depicted in a similar manner as that of the rectangular or disc earth synthetic model (see Section 2.4.2). In this case the sun and the moon is encapsulated within the earth's dome. When asked to show where the sun or the moon was in relation to the earth, participants FFR5 and FMR6 placed the sun and the moon directly on top of the clay model of the earth with no distance between the earth and the sun or the moon.

When they explained their reasoning it was clear that they formulated a disc earth synthetic model of the interaction between the earth, the sun and the moon.

Figure 4.5: Participant FFR5's depiction of the relationship between the earth, the sun, and the moon

Sun and moon are antithetical

For 6 of the participants the sun and the moon where always placed on opposing sides of their clay model of the earth. It was seldom seen that the sun and the moon would appear on the same side of the earth. Figure 4.5 is also showcases this response.

Category CIR3. Conceptual expression is somewhat normative.

There were 11 cases where the participants showed a more normative understanding of certain concepts. These were grouped in two categories.

Three-dimensional view of celestial bodies

In eight instances the participants showed a three-dimensional understanding of celestial bodies. Participant FFR5 depicted the earth as a white ball. Even though the colour chosen to represent the earth was naïve the three-dimensional shape of the clay was more normative. This same participant depicted the sun as a three-dimensional figure but made a two-dimensional crescent shaped model of the moon. Participant FFR2 chose to make a sphere shaped sun but made a flat model of the earth. Participant FMR3 made his model of the sun a three-dimensional sphere but also chose to make his model of the earth flat and square.

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Relationship between colour and characteristic

During the interview with the Grade R participants there were three instances where the participants realised a connection between the colour of an object and the characteristic of that object. Participant FFR3 showcased this in her answer to the question on why she chose yellow as the colour of the sun. She responded: “The sun is yellow and is so bright that it blinds your eyes. Yellow is brighter than all the other colours.” This shows that the participant made a connection between the colour yellow and the characteristic of brightness. Participant FMR6 explained that “It [the colour yellow] makes the earth get hot.” This shows that the participant made the connection between the colour and the characteristic of temperature.

Category CIR4. Connections to other subjects, specifically geometry.

During these interviews there were 35 instances where the participants used vocabulary that showed a pertinent connection to other school subjects. A connection to geometry was the most frequent connection observed. This category is broken down into three categories.

Geometric description of the earth and sun

When asked to explain what shape they chose to depict the earth or the sun the participants used vocabulary associated with geometry. Examples of these responses include “It [the earth] is a rectangle.” (FFR1); “It [the earth] is a circle.” (FFR2); “The earth is big and round.” (FFR3); and “The shape [of the earth] is square.” (FMR3). On four occasions the participants added rays to their models of the sun. When asked to explain what these rays were they responded: “When you draw the sun you make a circle and triangles or sticks or lines.” (FFR1); “The sun is round and on the sides there are shapes, triangles.” (FFR3); the sun is a “circle and there are sticks.” (FFR5); and “The sun has got triangles.” (FMR5).

The moon is crescent shaped

All participants except one chose to depict the moon as a crescent. It was only participant FMR2 who chose to depict the moon as a flat circle. None of these participants could use suitable vocabulary to explain their reasoning for choosing this shape. The responses varied from “This is how the moon is.” (FFR1); “I like to make it like this.” (FFR2); and “I like it. The moon is a triangle.” (FFR4); to “That is the shape of the moon. It is oval." (FFR3); "That is the shape of the moon. It is something that is crooked." (FFR5); and "The moon is like this. It is white. It is the moon shape. Shoes have a shape like this."

Description of the phenomenon is based on observable characteristics

There were 12 instances where the participants merely described the observable characteristics of a phenomenon when asked to explain their reasoning. When asked to explain their choice of colour when depicting the sun they merely stated that "the sun is yellow" (FFR1, FFR2, FFR4, FMR3) without elaborating. A similar response was given when asked to explain their choice of colour when depicting the moon. Participants FFR2, FFR3, FFR5, FMR2 and FMR5 responded by saying that the moon is the colour they chose.

Category CIR5. Strong sense of self (egocentric expression).

Many of the participants exhibited a strong sense of self when answering the questions. I could identify 11 instances where egocentric considerations and the participants' individuality was the major consideration behind their actions and explanations. Participant FMR2 chose the blue clay to make his model of the earth. When asked to explain his choice he simply answered "I like the colour blue." Participant FMR5 chose the brown clay to make his model of the earth and expressed that "*I* see that colour. *I* took this colour." When choosing the shape of the sun participant FFR2 said "The sun is a circle. I like it this way." Similarly participant FFR4 answered that "I like it. The moon is a triangle" when asked to explain why she chose to depict the moon with blue clay and shaping it as a crescent.

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Codes and categories as generated from the Grade R individual clinical interviews on vitalist biology.

Table 4.6: Results of data analysis of Grade R individual interviews on vitalist biology

Primary Code (n = frequency)	Secondary Code	Category
Groups are unequal (5)	No clear distinction between the 2 groups (5)	**CIR6.** Vitalist biology is not a consideration in classification (5)
Picture stays here (3)	Habitat as consideration for classification (3)	**CIR7.** Ecological factors are considered in classification (6)
The sun changes position during the day (3)	Relationship between elements used for classification (3)	
Groupings according to colour (4)	Colour as consideration for classification (4)	**CIR8.** Superficial considerations for classification (4)
Explains by describing the pictures (5)	Difficulty explaining reasoning (5)	**CIR9.** Limited vocabulary inhibits explanations (5)
2nd attempt group numbers is same as interviewer (6)	Learners attempt to mimic the interviewer (6)	**CIR10.** Learners attempt to mimic the interviewer (6)

Category CIR6. Vitalist biology is not a consideration in classification.

During this activity it was clear that the participants did not consider any of the vitalist considerations when grouping the images. Five of the participants had no clear distinction between their own groupings. It was as if they formed their own smaller groups within the two larger groups. The expectation was that the participants would form two groups of images separated on the grounds of their vitalist characteristics. Participant FFR5 came close to making a distinction based on movement in that she referred to her grouping as “These are all things that walk.” However, her second group included plants which she grouped together with rocks and explained her reasoning as “Everything [in this group], they all start from the bottom.” Here she referred to growth of fruit on trees. Except for these few vitalist characteristics none of the other participants made mention of any characteristics that could be associated with the characteristic of living organisms.

Category CIR7. Ecological factors are considered in classification.

It was interesting to note that the major considerations for the grouping of the pictures were based on ecological factors such as habitat and interaction between the various ecological entities, both biotic and abiotic. Participant FFR4 made an ecological connection between the image of the insect and the soil as well as a connection between the fish and the water. She said: “The insect goes with the ground because it lives on the sand.” She also referred to the fish and the water by saying: “Fish, the small fish live inside the water.” Participant FFR5 made a connection between the image of the tree and that of the soil by noting that the tree grows in the soil. She said: “Tree, it is the one that start. It starts properly. The one that grows from small to big. It grows and then we can have apples or peaches or bananas.” She also grouped the rocks with the soil and the tree and explained that “Rocks, they are always on the ground. Everything, they all start from the bottom.” Another connection between the soil and, this time, the chameleon was made by participant FMR6 in that he said: “It [the chameleon] is at the bottom. It stays, sits at the bottom on the ground.” The same participant grouped the image of the whale and the image of the water together saying that: “It [the whale] stays in the water.” Similarly participant FFR3 grouped the image of the water with that of the fish and said: “The water goes with the fish.” Implying that the two should be grouped together as the fish lives in water.

During the second episode of this part of the interview, where the interviewer grouped the images ‘correctly’, we heard more responses that emphasised the ecological considerations of the participants. Participant FFR1 saw that the images of the cow and the grass were placed in separate groups but saw that the image of the cow included the grass that it stood on and subsequently responded: “The cow eats the grass.” This showed the participants understanding of feeding as a consideration for their groupings. Another example of feeding as consideration for their groupings was seen when participant FFR1 grouped the image of the insect with that of the chameleon and explained that: "It [the insect] eats the [pointing to the chameleon]."

Category CIR8. Superficial considerations for classification.

During these interviews there were four instances where the participants' groupings were based on superficial considerations such as the images having similar colours or that the participant merely liked grouping the images together. Participant FMR2 grouped the image of water and that of the bird together and explained: "Because I like to put it here." Similarly he placed the image of the tree and that of the sun in the same group and said: "I like to put it here. The sun is about to set." This same participant also based some of his groupings on common colours. For instance, he grouped the image of the water and that of the cow together and explained that "It is connected because of colour" and later added "The water has white elements and the cow gives us milk." Participant FMR5 explained his groupings in that it had "three blue in each group." Showing that the colour of the images were a consideration for his groupings. Participant FFR2 mentioned in her explanation that "The colours make them the same." Participant FMR6 explained that grouping the images of clouds and that of water together was because "At the top there are white and blue things."

Category CIR9. Limited vocabulary inhibits explanations.

Throughout these interviews it was apparent that some of the participants had limited vocabulary to explain their reasoning behind certain decisions. This often manifested as the participant resorting to descriptions of the images instead of explaining their decisions. This occurred on five occasions. In attempting to explain why the interviewer grouped the images as he did, participant FFR4 could only describe the groups as "Here there are clouds. This side there are animals." The same participant continued explaining her own groupings by merely describing the images by pointing to the images and saying: "Sand and sun. Here the sun is setting and here it is rising. In the other group there is a bird. It is in the flowers."

Category CIR10. Learners attempt to mimic the interviewer.

As describe in Section 3.5 the interviewer shuffled all images following the participants' initial attempt at grouping the images and proceeded to 'correctly' group the images based on vitalist characteristics thus splitting the living from the non-living objects. But in each separate interview, only the arrangement of the cards were done differently to ascertain whether the participants tried to mimic the arrangement of the interviewer or if the participant memorised the placement made by the interviewer. There were five instances where the participants' initial groupings were uneven in number that changed to an even numbered split during their second attempt following the 'correct' arrangement of the interviewer. In most cases, especially that of participant FFR5, the arrangement of the images mimicked that of the interviewer. The actual images however, differed from that of the interviewer in all cases except that of participant FMR6. The explanation however of this participant did not indicate that he comprehended the reason for the two different groups of images.

4.3.2 Grade 3

Codes and categories as generated from the Grade 3 individual clinical interviews on observational astronomy.

Table 4.7: Results of data analysis of Grade 3 individual interviews on observational astronomy

Primary Code (n = frequency)	Secondary Code	Category
It is like that / That is how it is (5)	Difficulty explaining reasoning (5)	**CI31.** Limited vocabulary inhibits explanations (5)
Earth Shape is 2D (4) Earth is flat (2) Sun is 2D (5) Moon is 2D (3)	2 Dimensional view of celestial bodies (14)	**CI32.** Conceptual expression is naïve (24)
Sun has rays (4)	Solar rays are made visible (4)	
Sun position is on top of / touching the earth (1)	Rectangular or disc synthetic model of the earth (1)	
Moon opposite side of sun (5)	Sun and Moon are antithetical (5)	

Earth is 3D (5) Sun is 3D (4) Moon is 3D (3)	3 Dimensional view of celestial bodies (12)	**CI33.** Conceptual expression is somewhat normative (14)
Yellow shows temperature is hot (2)	Relationship between colour and characteristic (2)	
Earth is a circle (4) Earth is round (4) Sun is a circle (3) Rays are sticks / lines / Triangles (1)	Geometric description of the Earth and Sun (12)	**CI34.** Connections to other subjects, specifically geometry (29)
Moon is crescent (6)	Moon is crescent shaped (6)	
The sun is yellow (6) Moon is white (5)	Description of phenomenon is based on observable characteristics (11)	
I like to make it in this shape / colour (10)	Individuality as consideration for shape and colour (10)	**CI35.** Strong sense of self (egocentric expression) (10)

Category CI31. Limited vocabulary inhibits explanations.

As was the case with the Grade R participants, the Grade 3 participants also exhibited instances where their limited vocabulary inhibited their explanations. What is noteworthy however, is that the frequency of these responses where much lower in the Grade 3 sample. Where the Grade R participants had 15 instances, the Grade 3 participants only had five. When asked to explain his choice of colour when making the model of the sun participant FM37 responded: "The sun is like this." When participant FM33 was asked to explain why he placed his pin in the centre of the ball of clay he responded: "I don't know."

Category CI32. Conceptual expression is naïve.

There were 41 instances where the Grade R participants expressed their concept of a phenomenon in a naïve manner. With the Grade 3 participants the frequency reduced to 24 instances of naïve expressions. The same four categories that were generated during analysis of the Grade R data are also prevalent in the responses of the Grade 3 participants.

Two-dimensional view of celestial bodies

There were 14 instances where participants still depicted celestial bodies as two-dimensional figures. This is a reduced number in comparison with the 24 instances found in the Grade R sample. These participants still either depicted the earth, or the sun, or the moon as two-dimensional objects.

Solar rays are made visible

There were four instances where the participants made the solar rays visible. This is also reduced from the seven instances found in the Grade R sample.

Rectangular or disc earth synthetic model of the earth

In the Grade 3 sample there were only one participant who held the view that the relationship between the three celestial bodies were similar to that of the rectangular or disc synthetic model of the earth (see Section 2.4.2). In this case the sun and the moon is encapsulated within the earth's dome. When asked to show where the sun or the moon was in relation to the earth, participant FM36 placed the sun directly on top of the clay model of the earth with no distance between the earth and the sun and explained that the sun is "inside the sky of the earth."

Sun and moon are antithetical

For six of the Grade R participants the sun and the moon where always placed on opposing sides of their clay model of the earth. I saw in the Grade 3 sample that this occurred on five occasions. Within this sample the sun and the moon would not appear on the same side of the earth but poised antithetically.

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Category CI33. Conceptual expression is somewhat normative.

In the Grade R sample there were 11 cases where the participants showed a more normative understanding of certain concepts. Yet in the Grade 3 sample there were 14 instances where the understanding of the concepts were more normative but also qualitatively the vocabulary showed improvement. These instances were again grouped in two categories.

Three-dimensional view of celestial bodies

In 12 instances the Grade 3 participants showed a three-dimensional understanding of celestial bodies as opposed to the eight instances seen in the Grade R sample. Participant FF33 depicted the earth as a red ball. Even though the colour chosen to represent the earth was naïve the three-dimensional shape of the clay was more normative. However, this same participant depicted the sun as a flat disk with protruding rays and also chose a crescent shape for the model of the moon. In the case of participant FM32 he chose to make a sphere shaped blue earth but made flat disk models of both the sun and the moon.

Relationship between colour and characteristic

During the interview with the Grade R participants there were three instances where the participants realised a connection between the colour of an object and the characteristic of that object. In the Grade 3 sample there were only two instances. Participant FF34 showcases this in her answer to the question on why she chose blue as the colour for her model of the earth. She responded: “The world is blue and green in other places. The blue is water” This shows that the participant made a connection between the colour blue and the phenomenon that the planet appears blue due to the large oceans which contain water. A similar response was given by participant FM32. When asked to explain why she chose the colour yellow for her model of the sun participant FF34 explained that “The sun is yellow and when it is yellow it shows that it is in the morning and that it is hot.” This shows that the participant made the connection between the colour and the characteristic of temperature.

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Category CI34. Connections to other subjects, specifically geometry.

During the interviews with the Grade 3 sample there were 29 instances where the participants used vocabulary that showed a pertinent connection to other school subjects. Similarly the Grade R sample showed 35 instances of the same. During the interviews with the Grade 3 sample the connection to geometry was also the most frequent connection observed. This category is broken down into the same three categories as with the Grade R sample.

Geometric description of the earth and sun

When asked to explain what shape they chose to depict the earth or the sun these participants, as with the Grade R participants, still used vocabulary associated with geometry. Examples of these responses include "The world has a roundish shape." (FF34); "Everything is square everywhere." (FF35); "It [the earth] is round." (FM31); and "The earth is a circle." (FM33). It occurred on five occasions that the participants added rays to their models of the sun. When asked to explain what these rays were they responded: "I think the sun is yellow and has lines around." (FF31). The other four participants could not explain what these rays represented. When describing the shape of the sun the participants responded by saying: "The sun is also round." (FM31); "The sun is a circle when you look at it." (FM32); and "The sun is a circle." (FM37).

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Moon is crescent shaped

As opposed to the Grade R sample we see more of the Grade 3 participants choosing to not shape their model of the moon as a crescent. But the majority of the Grade 3 participants still shaped their model of the moon as a crescent. Participants FF32, FM31 and FM 32 chose a flat round disk shape as the shape of their model of the moon. It was only participant FF35 who made a three-dimensional, spherical model of the moon. Interestingly she chose to make her model blue, stating that "The moon is blue." The chosen vocabulary of the explanations of the participants were an improvement on what was seen during the same explanations in the Grade R sample. The responses were varied but still showed greater reasoning: "I've done this in Grade R and Grade 1." (FF33); "The moon at night we see at top and it looks like a banana." (FF34); and "At night it appears this shape." (FM36). The responses from the participants who did not choose a crescent shape also showed greater use of vocabulary i.e. “When you look at the sky, at the top, the moon is round.” (FF35).

Description of the phenomenon was based on observable characteristics

There were 11 instances where the participants merely described the observable characteristics of a phenomenon when asked to explain their reasoning as opposed to that of the 12 instances observed during the Grade R interviews. When asked to explain their choice of colour when depicting the sun the participants still only stated that “the sun is yellow” (FF33, FM31, FM32, FM36) without elaborating. A similar response was given when asked to explain their choice of colour when depicting the moon. Participants FF34, FF35, FM32, FM36 and FM37 responded by saying that the moon is the colour they chose.

Category CI35. Strong sense of self (egocentric expression).

As with the Grade R sample we still see many of the participants exhibiting a strong sense of self when answering the questions. With the Grade 3 sample I could identify 10 instances where egocentric considerations as well as the participants’ individuality were the major consideration of their actions and explanations. Participant FF33 chose the red clay to make her model of the earth and when asked to explain her choice she responded “I like to mark with this colour in class” and in her explanation of choosing blue for her model of the moon she responded: “I like to wear the colour blue and a blue cap. I’ve never seen a blue moon.” Similarly participant FM33 chose the green clay to make his model of the earth and expressed that “*I* wanted the earth to be green. The earth is blue but I wanted to make it green.” And when he was asked to explain his choice of white for the colour of his model of the sun he added “I like this colour too. The sun is yellow.” This same individual chose to make his model of the moon red and explained that “I wanted it [the moon] to be like this. I like the colour red. The real colour of the moon is blue.” When choosing the shape of the earth participant FF33 and FM37 said “I like this shape.” In her explanation of her choice of shape for the model of the sun participant FF35 answered that “I just like this shape.”

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Codes and categories as generated from the Grade 3 individual task-based clinical interviews on vitalist biology.

Table 4.8: Results of data analysis of Grade 3 individual interviews on vitalist biology

Primary Code (n = frequency)	**Secondary Code**	**Category**
Groups are unequal (5)	No clear distinction between the 2 groups (5)	**CI36.** Vitalist biology is not a consideration in classification (5)
Picture stays here (3)	Habitat as consideration for classification (3)	**CI37.** Ecological factors are considered in classification (6)
The sun changes position during the day (3)	Relationship between elements used for classification (3)	
Groupings according to colour (4)	Colour as consideration for classification (4)	**CI38.** Superficial considerations for classification (4)
Explains by describing the pictures (5)	Difficulty explaining reasoning (5)	**CI39.** Limited vocabulary inhibits explanations (5)
2nd attempt group numbers is same as interviewer (6)	Learners attempt to mimic the interviewer (6)	**CI310.** Learners attempt to mimic the interviewer (6)

Category CI36. Vitalist biology was not a consideration in classification.

As with the Grade R sample it was again clear that the participants did not consider any of the vitalist considerations when grouping the images. Five of the participants had no clear distinction between their own groupings. Participant FM31 was the only participant to notice that the intended distinguishing factor between the images was based on the fact that some images were of living organisms and other images were of non-living objects. After the interviewer arranged the images as was intended, participant FM31 explained that “all these [pointing to one of the groups] things are alive. All of these [pointing to the other group] are not alive.” Participant FM31 was also the only one in the entire sample to correctly rearrange the images during his second attempt in the intended groups. When asked to explain his reasoning he responded “You [the interviewer] showed me that these are alive and these are not alive.” The only other instance of a participant noticing a vitalist characteristic came from participant FF33 who made mention of cows eating grass but did so in an attempt to describe what she saw in the image instead of using feeding as vitalist characteristic to distinguish it from other images.

Category CI37. Ecological factors are considered in classification.

In the sample of Grade 3 participants we, once again, see that ecological factors, such as habitat and interaction between various ecological entities, both biotic and abiotic, are a greater consideration as distinguishing factor between the images than vitalist characteristics were. Participant FF31 mentioned that her groups were based on cohabitation and stated that it “looks like they [the images in one of her groups] belong here and they live in one place.” Participant FF33 showed a connection between the image of soil and that of water and concluded that these go together because “the water is connected with the sand and they create mud.” The consideration of habitat was again mentioned by participant FF34 when she explained that “sometimes these [insects] live [pointing to the images of the sand, soil and trees].” And also saying that “other animals, you can find them living outside of water. This was further supported by participant FM32 when he pointed to the image of the fish and that of water explaining “it [the fish] stays in the water.”

During the second episode of this part of the interview, where the interviewer grouped the images as intended, we again heard more responses that emphasised the ecological considerations of the participants. Participant FF34 tried to explain the groupings of the interviewer by saying: “I think that you put these because it stays here. This one [pointing to the cow] likes to sleep here on the grass.” Participant FM32 made a distinction between the two groups based on the first being possible habitats for animals and the other as a grouping of all the animals. He said: “This side, animals stay on earth and in the water. Other group is animals. It is grass and trees.” Participant FM33 seemed confused by the interviewers groups as he tried to explain the interviewers reasoning: “I don’t know. This one [group] is not the same [pointing to the other group]. This is water and here, there is grass inside. But this one [whale] stays in water and they [fish] also live in water." This showed that he wanted the image of the water and that of the fish and the whale to be grouped together.

After rearranging the images into two groups during their second attempt, some of the participants made further mention of the habitats of the animals by still grouping some animals with the non-living objects or environments where they believed these animals should live. Participant FF34 still grouped the image of water and that of the whale together saying "This one [whale] is always in the water." Participant FM32 solely used habitat as distinguishing factor as explanation of his groupings during his second attempt. He said: "These [pointing to the image of the whale and that of the fish] stay in the water. This [pointing to the image of the cat] stays in the house and other places. This [pointing to the image of the insect] stays in the sand."

Category CI38. Superficial considerations for classification.

As with the Grade R interviews we see similar superficial considerations for some of the groupings made by the Grade 3 participants. These considerations include the images having similar colours or that the participant liked grouping the images together. Participant FF35 matched the colours in the images and said: "This one [pointing to the image of the plume of white smoke] is white and the clouds are also white. This one [pointing to the image of the chameleon] is green and the grass is also green. The colours are similar." The same participant explained that the interviewers choice of groups were also based on colour by saying that "these ones [pointing to the group on her left] match. This one [pointing to the grass] has green. These [not clear to which individual image she is pointing] are similar. These ones [pointing to the sand and the soil] have the same colours." During his second attempt at arranging the images in two groups, participant FM33 explained the distinction he made between the two groups as "these [pointing to the group on his left] are soft when you touch them. These [pointing to the other group] are hard when you touch them". After his second attempt participant FM37 explained that he chose to group the images the way he did by saying "I like it this way."

Category CI39. Limited vocabulary inhibits explanations.

In much the same way as the Grade R sample there were five instances during these interviews that showed how some of these participants could not manage to explain their reasoning. This, again, manifested as the participant resorting to merely describing the images instead of explaining their decisions. It is however, noteworthy to observe the improvement in vocabulary, as can be expected, in the Grade 3 sample as opposed to the vocabulary of the Grade R sample. Participant FF33 could not explain her reasoning behind her decisions and resorted to describe the images. She answered in such a way that showed a stream of consciousness as if to attempt to satisfy the interviewer by talking 'enough'. She answered "There are trees that are green. The chameleon will change colour. Animals are always digging and coming outside. Cows like to eat grass. At the bottom there is sand and people put stones on top of the sand." In much the same way participant FM36 responded "This is where the sun is. It [pointing to the image of the cow] is an animal." When he was explaining the interviewer's groups he continued describing the images, saying "These is animals here [pointing to the group to his left] and flowers and trees." He described the other group by saying "There are clouds and the sun. Here is late afternoon. Rocks, water and the sun."

Category CI310. Learners attempt to mimic the interviewer.

In exactly the same way that some of the Grade R participants attempted to mimic the interviewer's groups, we see more instances of the Grade 3 sample attempting to do the same. There were, again, five instances where the participants' initial groupings were uneven in number that changed to an even numbered split during their second attempt following the 'correct' arrangement of the interviewer. In most cases the arrangement of the images mimicked that of the interviewer to such an extent that even the tenth card was placed in the same position as the interviewer had placed his.

Figure 4.6: Example of interviewer's groupings showing the placement of the tenth card in the centre row

Figure 4.7: Example of the interviewer's groupings showing the placement of the tenth card in different positions

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The actual images, as was the case with the Grade R interviews, differed from that of the interviewer in two instances, with three participants being able to group the images correctly as the interviewer did.

4.4 THEMES IDENTIFIED FROM THE DATA ANALYSIS

In this section I summarise the various themes generated from the data categories, mindful of the requirements for trustworthiness, of which coherence of findings are crucial. (Le Compte & Preissle 1993; Miles & Huberman 1994, 2013). In total 40 categories were created and in order to connect these conceptually, I have decided to further collapse the categories into themes according to the commonalities of their origin. I end this section by drawing the major themes of this study which will be discussed in Chapter 5.

4.4.1 Children hold naïve theories

- **SSR2.** Celestial bodies are personified
- **SSR3.** Description and explanation of phenomena is naïve
- **SSR5.** Objects are classified and described using geometrical shapes
- **SSR6.** Vitalist discourse relates to obvious observable characteristics and is naïve and ‘egocentric’ (or anthropomorphic)
- **SSR7.** Classification / categorise according to colour
- **SS32.** Description and explanation of phenomena is naïve
- **SS33.** Celestial bodies are personified
- **SS34.** Objects are classified and described using geometrical shapes
- **SS36.** Objects are classified and described using size and colour
- **SS37.** Vitalist discourse relates to obvious observable characteristics and has progressed but is still not normative and closely related to human life.
- **SS38.** Plants are generally considered as non-living
- **SS39.** Theory of matter is naïve
- **CIR2.** Conceptual expression is naïve

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- **CIR6.** Vitalist biology is not a consideration in classification
- **CIR8.** Superficial considerations for classification
- **CI32.** Conceptual expression is naïve
- **CI36.** Vitalist biology is not a consideration in classification
- **CI38.** Superficial considerations for classification

4.4.2 Personal experience of natural and sociocultural phenomena hold sway in their theories

- **SSR4.** Children relate phenomena to social reality
- **SSR8.** Children relate phenomena to their own experience
- **SS310.** Sociocultural component of natural objects
- **SS312.** Objects that are familiar are classified and described using terminology
- **CIR4.** Connections to other subjects, specifically geometry
- **CI34.** Connections to other subjects, specifically geometry
- **CIR5.** Strong sense of self (egocentric expression)
- **CIR10.** Learners attempt to mimic the interviewer
- **CI35.** Strong sense of self (egocentric expression)
- **CI310.** Learners attempt to mimic the interviewer

4.4.3 Limited vocabulary inhibits expression of concepts

- **SSR1.** Limited expressive vocabulary inhibits explanations
- **SS31.** Limited vocabulary inhibits explanations
- **CIR1.** Limited vocabulary inhibits explanations
- **CIR9.** Limited vocabulary inhibits explanations
- **CI31.** Limited vocabulary inhibits explanations
- **CI39.** Limited vocabulary inhibits explanations

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4.4.4 Conceptual expression was somewhat normative in older children

- **SS35.** Changes in phenomena are observed and noted
- **SS311.** Learners note relationships between natural phenomena
- **CIR3.** Conceptual expression is somewhat normative
- **CIR7.** Ecological factors are considered in classification
- **CI33.** Conceptual expression is somewhat normative
- **CI37.** Ecological factors are considered in classification

In Figure 4.8 I draw the relationship between the themes from the data with the most expressed finding, that children hold naïve concepts, in the centre of the diagram with the other prominent themes in proximity to the central theme. In Chapter 5 I will discuss the connection of these themes and how these themes relate to the conceptual framework of the study.

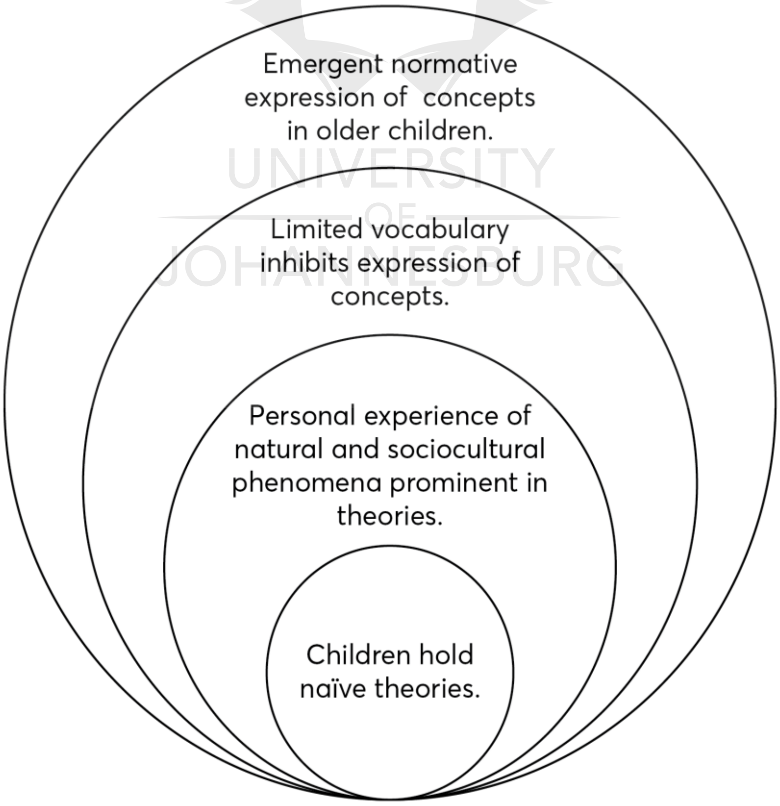

Figure 4.8: The connection of sociocultural experience, language and the expression of naïve concepts

4.5 SUMMARY OF CHAPTER

The development of normative science concepts, particularly a normative theory of vitalist biology and observation astronomy, requires of the individual to dedicate domain general as well as domain specific resources to learning about these concepts. The results as described in this chapter have given a snapshot of the state of the participants' conceptual networks. It was found that the children mostly hold naïve concepts of vitalist biology and of observational astronomy and that their experiences, or lack thereof, of these natural phenomena, play a role in the development of these concepts. Despite their naïve concepts some individuals made some progression toward a normative understanding of some of the concepts, but this was only evident in a minority of children.

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CHAPTER 5

DISCUSSION OF FINDINGS

5.1 INTRODUCTION

This study began with a reference to diSessa's proposal for granular investigations of conceptual change (diSessa 2002). Thus, when I asked the research question, 'what concepts do Grade R and Grade 3 learners hold when they explain scientific phenomena?' - I responded with the plan of a qualitative case study, the design of which is described in Chapter 3. The analysis of data would thus conform to what diSessa (2002) argued for, because I would strive to search for minutiae in the children's expression. I found specific granular aspects of the conceptual development of the young people in this study. They expressed the type of naïve concepts and intuitive theories that authors such as Carey (2009), Gopnik (2011), and Vosniadou (2007) have investigated. Added to that, it is evident that their everyday experience and their social context featured in their expressions.

The main finding of the study is, for teacher educators, somewhat disconcerting – namely that young children in a well-functioning public school, with ample material and human resources, do not learn much about the topics of the science curriculum over a period of three years. They are unlikely to be able to engage with the Grade 4 curriculum, in which they will encounter natural sciences and technology as a subject. The findings of this study suggest that these young children simply do not yet have a firm grasp of the basic concepts that were investigated in the study and that there was not a noteworthy difference between the younger and the older children, when judged by the task-based interviews that were conducted in the second phase of the study.

For the remainder of this chapter I will discuss the significance of the themes, as derived from the data analysis in Chapter 4, within the framework of the *hierarchy of mental entities*, as described in Chapter 2, and of activity systems analysis (ASA), described in Chapter 3. These were the dual analytical frameworks which I now invoke in the interpretation of the findings.

5.2 THE THEMES

In Chapter 4 I described the data analysis process. I showed how the 'raw' data in each data set across the two phases of inquiry were awarded primary codes, and how these were then clustered into secondary codes. These codes were amalgamated according to their conceptual connectedness and from each of these groupings I abstracted 40 categories in total. These categories were then further grouped (Section 4.4) to formulate four overarching themes, which constitute the findings of the study. The main finding is that there is limited progression over the three-year period (from Grade R to Grade 3) of children's conceptual development of observational astronomy and vitalist biology. The study was not intended to be longitudinal, but in the cross-sectional data there is evidence to claim that the Grade R children and the Grade 3 children do not differ much in their expression about the two topics of the inquiry. Also, the interviews of the first phase of the study, captured the Grade R cohort of 2014, from which a sample was randomly assigned for the second phase in 2017, when the participants in the sample were in Grade 3. There are, thus, elements of a longitudinal view, which I did not interrogate, due to the fact that the sample of 2017 was not the exact sample of 2014. This was because in 2014 the utterances were from individuals who did not necessarily form part of the random sample in 2017. In hindsight, this was a design flaw.

In addition, of course, this was not a study with the use of a fixed, validated instrument that showed progression in any standardised way, and the data that captured the children's concept formation are at best descriptive. Nevertheless, there is sufficient warrant to argue that the Grade R children's concepts and theories did not differ much from those of the Grade 3 children in the same school, with similar home backgrounds.

5.2.1 Situating the themes within the hierarchy of mental entities

The work of various researchers of children's theory formation was utilised to design an analytical tool for the study (Carey 2009; diSessa 2002; Barner & Baron 2016), which I refer to as a 'hierarchy of mental entities' (Fig.2.3). In this diagram I propose the relationship between the various levels in the 'hierarchy', with 'mega' conceptual structures as the 'top' structure. I compare this with what Carey (2009) would refer to as a 'conceptual system'. In the rest of this section I view each finding through the lens of this heuristic and describe the themes as I located them on each one of the levels of the hierarchy. Figure 5.1 shows an overview of the interpretation of the findings according to this heuristic. I mark the locations of each theme on one or more of the 'levels.'

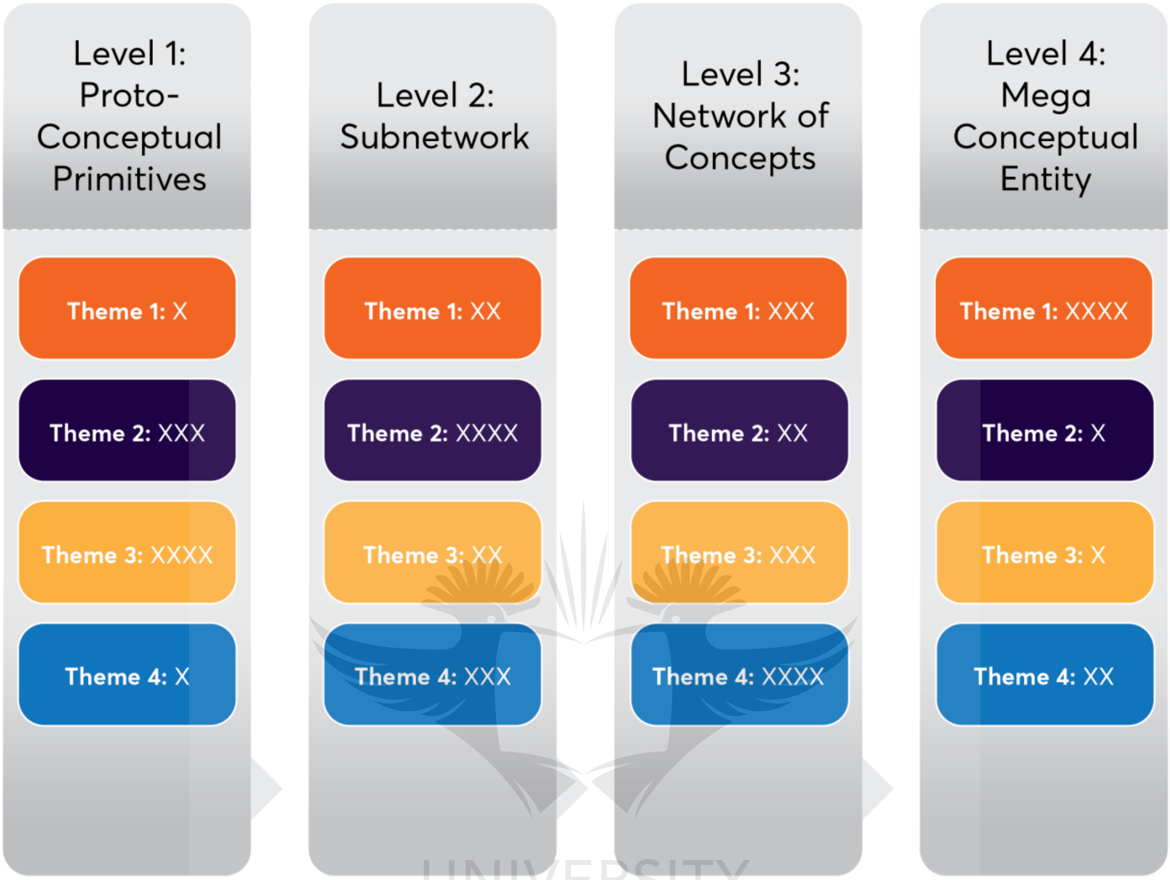

Figure 5.1: Situating the themes within the hierarchy of mental entities

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This figure represents the most pertinent locus of each main theme in the hierarchy. The number of 'Xs' indicate the relative magnitude of the manifestation of the themes.

Theme 1: Children hold naïve concepts

This theme was derived from 18 categories, referred to in Section 4.4.1 and shows the instances in all four data sets where the participants demonstrated a naïve understanding of natural phenomena. In most cases the explanations which the participants gave did not resemble the normative or scientifically accurate explanations at all, but exhibited a myriad of naïve and intuitive 'misunderstandings' and 'misconceptions', or, as some theorists would argue, 'concepts in formation'

(Vosniadou 1994; Carey 1985). Many of these explanations were similar to the *synthetic models*[5] as described in Section 2.4.2.

Before embarking on this study, I hypothesised that the Grade R learners would hold naïve concepts, but I expected the Grade 3 sample to demonstrate fewer such naïve conceptions and show some cognitive move or progression towards normative concepts. By comparing the Grade R samples to the Grade 3 samples, it is evident that some individual children have progressed in terms of conceptual understanding by the time they reached Grade 3, but that the explanations given by them still do not resemble the normative concept in any way. These individuals were also in the minority as most of the participants in the Grade 3 samples still demonstrated their naïve concepts in much the same way as the Grade R participants, using similar linguistic expressions.

When interpreting this theme, and using the analytical tool I have devised, I argue that the expression of mega-conceptual structures, such as theories, cannot be expected to be normative when knowledge, situated on the underlying levels within the hierarchy, are underdeveloped. This means that children learn, based on what they know. The notion of the 'learning paradox' comes to mind (Bereiter 1985; Prawat 1999). "Efforts to explain learning as a constructive process run into the paradox of having to attribute to the learner prior knowledge that is at least as complex as the new learning to be explained" (Bereiter 1985:201).

Bereiter (1985) argues that knowledge 'under construction' is as multi-layered as previously constructed (prior) knowledge. Also, a constructivist epistemology assumes that prior knowledge 'connects' with new knowledge (Von Glasersfeld 1995; Piaget et al. 1978; Phillips 2000). I would argue that the 'connection' is a missing link in trying to get a clear picture of how early grades children learn about the natural world. The data of this study show, quite pertinently, that, although the Grade 3 children had been exposed to some new knowledge in school, it was not connecting with what they knew and believed – in fact, it would seem that their naïve ideas had been firmed up by what they had encountered at school (and elsewhere).[6] The children were holding on to their naïve concepts of life and what they 'observed' of the earth

[5] Interestingly, in impromptu testing of undergraduate students and Honours students in the teacher education programmes, similar naïve/intuitive theories were held. Education at school did not change their conceptual systems

[6] It could well be that the teachers had not developed normative theories, much like the students I referred to in a previous footnote.

and the solar system. In studies by Carey et al. (2015), Zaitchik et al. (2016), and Vosniadou and Brewer (1992) the findings were similar. It could be that this is a 'developmental stage' for humans to move through to understand their natural environment. There is some universal applicability to the current view of conceptual development, regardless of context, but that the nuances of the differences between the various studies might depend on the exposure that the children have had to specific natural phenomena and to instruction (Ozdemir & Clark 2007). My sense is that in the case of this thesis study, the teaching was not addressing the naïve concepts, possibly because the teachers did not inquire into children's existing knowledge or held a view of child learning that does not allow for this type of exploration. The position of the study is that if teachers knew more about children's 'theories-under-construction', they would adapt their teaching to form the constructivist bridge for children's journey to normative concepts and theories.

Several authors (Legare & Clegg 2015; Gopnik 2011; Naude 2015) agree that children between the age of six and nine years have the causal reasoning skills to interpret novel experiences in a way that can adapt their initial conceptual system through cognitive processes such as bootstrapping (Carey 2009, 2016; Barner & Baron 2016) and other learning mechanisms (Section 2.3.3). All the participants of this study showed their ability to reason causally and they interacted with the interviewers comfortably. They appeared 'open' to learn and to adopt new terminology and should, ultimately, be able to change their knowledge and thus their concepts/theories, if given suitable scaffolds to build new knowledge. And that, in my view, would depend on teachers who know not only how to teach and what to teach, but who also know how children learn.

The children in this study may not have received worthwhile instruction, or may not have had informal discussions on the topics in everyday encounters. One would expect this type of informal exposure in a social context where the solar system and biology are mentioned and taught and where children learn in a sociocultural set-up that somehow makes them aware as informal apprentices, such as Rogoff (1990), Lave (1988), Roth (2014), and others have argued. When learners are not exposed to some such learning opportunities, whether they be formal or informal, they are less likely to 'transform' their conceptual systems towards a near-normative understanding of natural phenomena. The prevalence of teacher- centred science teaching methods in the foundation phase is possibly to blame, as is the largely facts-based science teaching, which does not contribute to theory formation or conceptual change. For instance, they learn an *aide de memoire* to remember the order of the planets in distances form the sun, but do not learn the concept of the solar system itself.

The children in this study are in a public school, where teachers have a very strictly 'controlled' curriculum, with only a few science concepts listed in the content. The allocation of teaching time of these concepts is overshadowed by the requirements to teach mathematics and language (Mostert 2018). The teaching 'duties', and in particular the pressure to continually assess and record performance, along with a range of other non-teaching related responsibilities of the teacher, does not allow the teacher the freedom and time to invest in every lesson (Radebe 2018; Ntsoane 2018). In my observation at the school, the children mostly complete worksheets in workbooks to serve as proof that the teacher has 'covered' the content. This does not encourage deep learning and learners are left with their naïve understanding of science concepts, with which they then enter Grade 4. In this grade they are expected to know much more to begin with.

In this 'reduced curriculum' of the foundation phase, they simply cannot learn science, because science learning already requires major re-organising of the learners' knowledge base (Vosniadou 1996:99; Carey 2009). The current way of introducing science to young learners just does not make sense. In my view, the schools should have time for science demonstrations, *makerspace* activities, as well as brief excursions to the natural world outside the classroom, such as reported in the work of Roth (2014). If learners do not encounter learning experiences whereby their own beliefs (Level 2 in the hierarchy of mental entities) are challenged, they are unlikely to re-organise these beliefs.

This theme is most evident within Level 4 of the hierarchy of mental entities, but is most likely caused by underdevelopment of the lower levels. In my own theorising on this theme I would argue that science that is taught by factual knowledge will not overrule beliefs and ontologies that the children hold, but are likely to reinforce these. The 'crescent' moon (or the 'banana; moon) representation of children in this study is an example.

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Theme 2: Personal experience hold sway in their theories

This theme was constructed by connecting 10 categories that had captured participants' explanations and tasks, reflecting their personal experience of natural- (and interlinked) sociocultural phenomena. I have placed the greatest weighting of this finding on Level 2 of the hierarchy of mental entities, followed by Level 1. The influence of experience and interaction with the sociocultural- as well as the natural environment feature strongly in their conceptions and in the revision of their ontological beliefs (see Section 2.3.2). Chi (2009) argues that there is constant flux in children's 'favourite' beliefs. This flux is initiated when children experience a novel phenomenon that requires them to make sense of it and when the 'stability' of the held conceptual network is threatened, because the novel experience cannot be assimilated and then also not accommodated. The explanations and considerations of the participants showed that they valued knowledge from spheres of life other than that of science. I would argue that for many of the participants their considerations were mostly not due to a formalised view of science, but rather due to their own intuitive understanding of an interrelated whole with *themselves as the axis*. Most of the demonstrations and explanations of the participants were *egocentric*. It was also evident that the participants made knowledge connections with other subject areas, such as mathematics and art, which may have influenced their responses and interactions during the interview discussions and tasks. There were also instances where elements of the participants' symbols of everyday culture influenced their explanations, for example, the child who referred to the sunflower seeds as beads – an object closer to her world than the notion of seeds of a flower, which she has probably never seen. These experiential factors were evident in the explanations of the participants, which is not unusual for learners of any age-group, but which were particularly prominent in the data.

This finding required an additional analysis of the sociocultural environment in which the children grow up; in another part of this chapter (Section 5.2.3) I include an *activity system analysis* of the learning of science in the early grades in a school such as the one where this study was conducted, to invoke the societal, communal factors that are inserted into young children's learning (of science). This type of analysis is not unusual in studying organisations such as schools and is typically used in educational psychology, utilising the theory of Bronfenbrenner (1979) or the modality suggested by Vygotsky (1933, 1978, 1986) and elaborated by Engeström (1987).

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The environmental factors, specifically the status quo of the foundation phase curriculum, is not conducive to optimal conceptual development. The architecture of the curriculum indicates an isolated, disconnected approach to teaching science content when, by contrast, it is the nature of the individuals to find connectedness. This connectedness between the various learning areas found in the curriculum is seldom made explicit by the policy or by teachers, and flies in the face of what is required for conceptual change to occur optimally. Also, a fundamental tenet of 'social constructivism' (Phillips 2000) is the interrelatedness of the individual and the cultural milieu (Vygotsky 1978, 1987; Kozulin 1986; Rogoff & Lave 1984; Rogoff 1990). This has important implications for science education in the foundation phase and supports the argument for a more integrated approach to teaching science in the early grades.

Once teachers have identified what children already know - and what they *believe* - they could improve lesson design by utilising cross-cutting concepts between multiple disciplines or learning areas and incorporate these in lessons that aim to develop skills as well as address 'big ideas', a methodology known as three dimensional teaching (Erickson & Lanning 2014). If science is to have a greater focus in the foundation phase, it would need to fit within the greater constraints of the current curriculum without the need to revise the curriculum, as this would be too disruptive in a school system where change has become the curricular norm. Thus, by identifying the topics from science that connect with topics of language and mathematics, teachers would be able to integrate the teaching of these topics. This may address the issue of children's 'egocentric' nature and allow for learners to place themselves as the axis of the learning experience, while still being immersed in their cultural environment. This, then, could more closely mimic the life that they live outside of the classroom, ensuring that the transition from being outside the classroom to inside the classroom is as seamless as can be. The current trend of 'phenomenon-based' learning in Finland and Norway (Francis et al. 2013) is an example of a curriculum and pedagogy that puts experience and a specific phenomenon at the centre and truly exemplify teaching (and learning) 'across the curriculum. Silander (2015:1) writes:

> The phenomenon-based approach is anchored learning, where the questions asked and issues to be learned are naturally anchored in real-world phenomena, and the information and skills to be learned can be directly applied across borders between subjects and outside the classroom in situations where the information and skills are used (natural transfer).

Theme 3: Limited vocabulary inhibits expression of concepts

The categories mentioned in Section 4.4.3, where there were examples of participants not being able to express their reasoning sufficiently, showed up in this theme strongly. This was evident in both the Grade R and Grade 3 samples, regardless whether the participant chose to respond in isiZulu or English or in a code-switched rendering. In the Grade R sample there was a greater prevalence of this, which is to be expected, given that the Grade 3 children had longer to develop their vocabulary than the participants in the Grade R sample. This is further complicated by the arrangement that the language of tuition for the Grade R learners was exclusively isiZulu and that the language of tuition for Grades 1 to 3 includes English for some subjects such as mathematics, but, generally in the school, there is much code-switching and *translanguaging*. But, even so, children expressed themselves in non-fluent discourse. They often halted and could not find words to express themselves and struggled with verbs, specifically.

When children do not have the much needed vocabulary that could serve as 'placeholders' (Carey 2009) for their evolving understanding, it does not inherently imply that the child holds a naïve concept, but without sufficient expressive language competence, conceptual development can be compromised. Gopnik and Meltzoff (1997) argue strongly for a view of child development that relies on and expands linguistic competence. In Section 2.6 I discussed how language serves as a semiotic device that mediates the meaning making process and is a fundamental system of meaning making (Henning 2012; Henning & Dampier 2012; Odora-Hoppers 2005). Furthermore, if teachers are not adequately trained in the content and skills of science as well as the 'language of science,' it will not be possible for them to teach science for conceptual development.

The dominant locality of this theme within the hierarchy of mental entities is on Level 1. One of the proto-conceptual primitives is that of concepts as *a single lexical entity* that forms the placeholder structure (see Section 2.3). Words 'hold a place'.

Vygotsky (1986) describes this by referring to ‘pre-linguistic concepts’ and ‘pre-conceptual language’ – arguing that if the two ‘meet’ concepts get firmed up. Dowker and Nuerk (2016) and Levine and Baillargeon (2016) have shown how this phenomenon plays out in mathematics learning. If children aren’t exposed to terminology (as linguistic placeholders for developing concepts), they will not create the placeholder structure that serves as the primer for conceptual development. For example, if children learn the word ‘orbit’, they may not have any semantics for it (yet). But, when they ‘pretend’ play, to simulate the orbit of the moon around the earth in a playful way by, for instance, one child running around the whole class all bundled together as the plane earth in a tight circle, the placeholder word slowly acquires some semantics (Fig 5.2). Dowker and Nuerk (2015) refer to this as a ‘linguistic concept – the bridge from word to meaning. Carey would refer to this as conceptual development with a placeholder (which, according to her, can be a word, an image, a sound or any object).

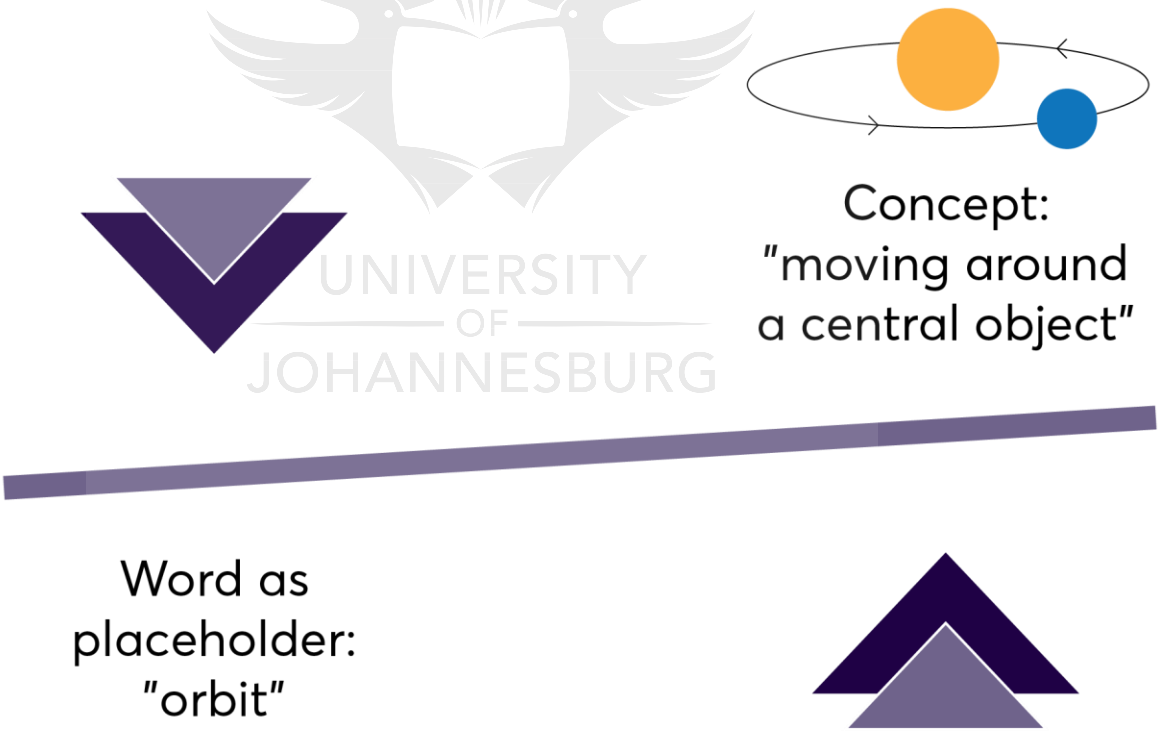

Figure 5.2: From placeholder to concept

Further to that, concepts on Level 3 would be greatly underdeveloped when the semiotics, or the signs and the symbols representing the beliefs (Level 2) are not challenged by contradicting, or substantiating, competing beliefs – if these could not adequately develop because of the lack of vocabulary and underdeveloped proto-conceptual primitives. This naturally has a 'knock-on effect' for the development of mental entities on the other levels of the hierarchy. If children did not have a meaning for 'orbit' as a verb representing a phenomenon and thus become a concept, they would be left in the dark and simply memorise a meaningless definition of 'the moon orbits around the earth". Of course, the meaning of earth would have to be clear, and in turn, the earth's orbit around the sun as well.

Theme 4: Emergent normative expression of concepts in older children

Six categories coalesced to constitute this theme, in which signs of a 'bud' of a concept (Vygotsky 1978:74) are noticed. It shows that some children have started to 'move' towards a normative understanding of the two natural phenomena. There was only one such instance in the Grade R sample, compared to five category instances in the Grade 3 sample. This is to be expected because, as time progresses, children are exposed to more instances that challenge their conceptual frameworks and they encounter more words as placeholders and also develop more general cognitive skills. It is difficult to determine whether these instances of emergent normative expressions are due to the tuition at school or whether this is due to external factors such as their interest in the topic or more regular exposure to the concept due to family interactions and everyday life, including television and the internet.

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Tuition seems an unlikely source of the learning, as the majority of Grade 3 participants still had not changed their expression and held naïve understandings. If their concepts had changed due to the tuition they had received, it would be reasonable to assume that most of the Grade 3 sample would express their understanding of the concepts in a similar manner – despite the small sample size, this is still a notable observation. Added to that, the instances of these emergent normative concepts, do not show many similarities or correlation with each other

When reading the foundation phase curriculum, it is notable that there are ample opportunities to incorporate the teaching of science concepts in lessons in other subjects, in other words, to utilise science phenomena as topic for integrated curriculum teaching. This would require all foundation phase teachers to have a holistic view of the progression of the entire foundation phase curriculum to identify these opportunities. Furthermore, teachers need to develop their PCK of science in order to adaptively connect science concepts to other topics in the curriculum. This, in turn, places a responsibility on foundation phase teacher training institutions to redesign their foundation phase programmes to include a greater focus on the teaching of scientific literacy throughout their curricula.

5.2.2 Dominant locus of impact

The discussion of the themes gives an indication of the major challenges to children's conceptual development of the two topics. I decided to conduct a secondary analysis of the data to triangulate within data analysis. I not only viewed these themes in isolation but also wished to find the average locality within the hierarchy of mental entities. Finding this locus of impact, I reasoned, would require a meta-interpretation of the findings and I used Figure 5.1 to serve as platform for a meta-interpretation. The highest concentration of X's would show the locality within the hierarchy of mental entities where the findings of this study had the biggest 'impact', or featured most strongly in the analysis. On this view I conclude that the locality of impact is greatest in level two and level three. This is understandable, given the constraints of this study; by design, the mega-conceptual structures were not investigated explicitly. The interview protocols were designed to explore the expression of the concepts (on Level 3) that the learners hold. It would therefore be ambitious to suggest that the findings of this study would show 'impact' on the mega-conceptual structures the most. However, all four themes featured on either the subnetwork on Level 2 or the network of concepts on Level 3.

Theme 1 shows that the children hold naïve concepts and that these concepts are based on the interconnectedness of their conviction to the ontological and epistemological beliefs that have developed due to their interaction with the natural and sociocultural world. I would argue that these beliefs are deeply entrenched because of the children's extended experiences within their unique sociocultural context. In this way Theme 3 and Theme 1 are interconnected and, even though the findings cannot confirm causality, it would stand to reason that a lack of exposure to science phenomena and scientific investigation, whether through play or discussion, would disadvantage the development of normative concepts.

5.2.3 Activity system analysis: learning as activity in a specific sociocultural system

In addition to the interpretation of the findings thus far and to further the analytical veracity of the study, I also conducted an activity system analysis, because it was evident that the challenges that young learners in this urban 'township' school in Johannesburg face systemic challenges that go beyond their individual learning and development capabilities. Thus, instead of citing the vast literature on poverty as factor in learning, which would not yield much original thinking on my part, I opted to do a systematic analysis of the children's learning activity system as per the tool that Engeström (1987, 2001) designed in 'third generation activity theory'. I wanted to use this thinking tool to gauge what systemic influences are arguably present in the children's learning. With this, I wished to 'tease out' or 'unpack' some of the *tensions* in their 'system' that could possibly inhibit science conceptual development (see Section 3.10). TI described the components of the activity system according to the ASA tool:

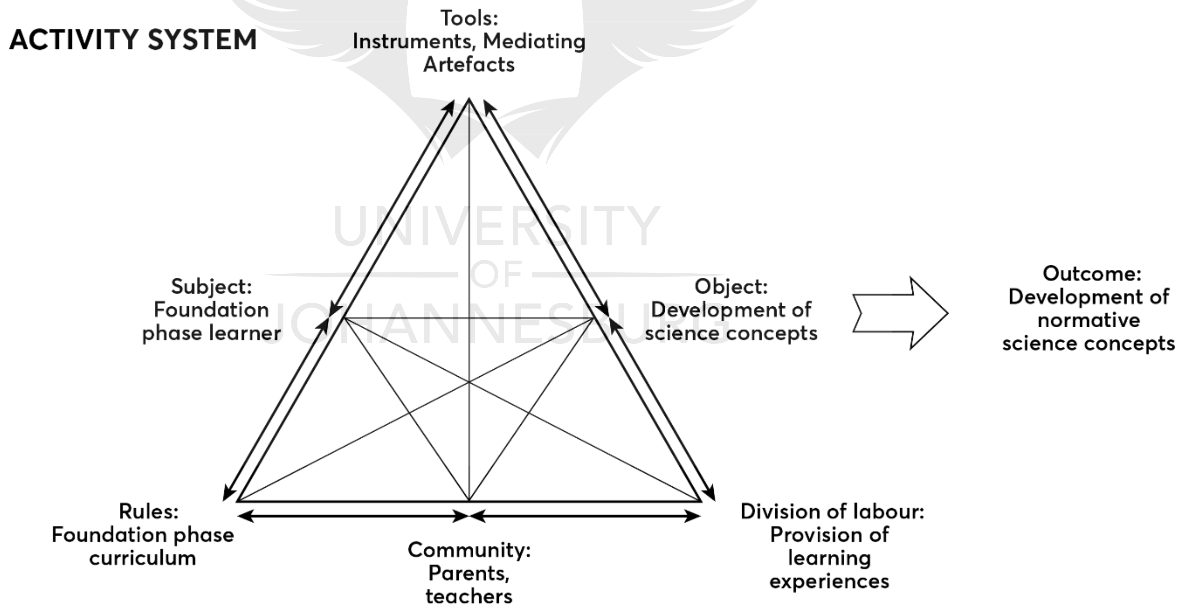

Figure 5.3: The activity system of learning science in the foundation phase

Studying the current state of foundation phase science education, including current practice and policy (see Section 2.7), assisted me in identifying certain 'tensions' in the hypothetical 'activity system' of science learning in a 'township' school. In this section I briefly mention these tensions to highlight the systemic challenges.

The desired *outcome* of the activity in the system of learning science in schools such as the one where I conducted my study is adequate progression in science concept development Grade R to Grade 3. This outcome was not met. I identified the tensions within the system, with the aim to suggest a feasible intervention.

The findings of this study show that there is tension between the *subject* of this study, the learner, and the *object* of this study, the learners' conceptual development. This is, of course, not the only locus of tension in the system but is an important tension to interrogate to determine whether this tension can be attributed to the ability of the children to comprehend the normative concepts at their stage of development, or whether the tension is a result of factors external to them, such as a reduced curriculum, or inept teaching. The discussion of the findings led me to conclude that the inadequate development of normative concepts cannot be solely placed on the cognitive ability of the learners, but that the contribution of tensions that are present in various loci in the activity system should be investigated. I have argued in this thesis that if teachers knew more about children's learning, they will be adaptive and adjust their teaching.

The *community* component of the analytic device also gives a 'gaze' (Wardekker 2008) on the development of concepts. The community in this system can be defined as the classroom and the school, as well as home life. Developing an interest in science as well as fostering values and attitudes toward science issues, as opposed to only learning factual knowledge, is not at the foreground of foundation phase teacher education programmes. I argue that by aligning foundation phase teacher education programmes with the *Bildung-Didaktik* traditions (Wang et al. 2018), as observed in Finland, foundation phase teachers would place greater value and importance on the learning of all facets of science. This could, in turn, create learning opportunities that would value not only factual science knowledge but also the skills, values and attitudes of science. Most foundation phase teachers have not received proper training on how to teach science and their lack of, or rudimentary PCK is a factor that adds to the tension between the division of labour and the subject in this activity system.

The *rules* component of the activity system gives a 'gaze' that shows added tension on the subject (the learner) either directly or indirectly. Given that the policies such as the foundation phase curriculum and teacher training curricula do not value the teaching of science to such an extent as it values the teaching of subjects such as math and language, this is not unexpected. These policies also do not make explicit the instances where content from different subjects can be taught in an integrated way.

The language of instruction as well as the lack of existing science terminology for African languages can be viewed as 'rules' as well as the 'tools' in the activity system that also add tension. The curriculum places expectations on teachers to use science terminology with which they are not comfortable and which is foreign to many children, especially those in Grade R.

5.3 CONTRIBUTION OF THE STUDY

This study contributes to the body of knowledge about early grades education and in particular to PCK of early grades science teaching. The study has also provided and in-depth analysis of a sample of children's learning and development, which would make useful reading for student teachers and for teachers who wish to expand their knowledge of child development and learning.

5.3.1 Knowledge synthesised: Conceptual development and conceptual change

Throughout this study, particularly in Chapter 2, I provide an account of literature about conceptual development and conceptual change, referring to several pertinent studies. I regard the heuristic that I designed as a useful tool with which to investigate concepts in science and in other domains and would hope to see it used in future studies (see Figure 2.3). This is a diagrammatic representation of how one can classify concept development. It is an amalgamation of the postulates of scholars who studied conceptual change theory and conceptual development. It illustrates the interactions and relationships between the various 'mental entities' and how these structures change during theory construction and revision. I discussed (Section 2.3.1) how the discourse and vocabulary around 'concepts' is used generally - given the colloquial use of the word and its often misuse. I have described the discourse and the associated semiotics of the various terminologies evident in the literature of conceptual development and have arranged these concepts within a novel framework which represents the hierarchy of 'mental entities'. This is, thus, a knowledge contribution that emerged in the study of a selection of the literature. The contribution is to the knowledge domains of children's theorising about science phenomena, the learning of science concepts in the foundation phase of the primary school, science talk for children in the classroom, and knowledge about what adults should know to understand children's thinking.

5.3.2 Methodological contribution

The methodological design of the study held many risks, given the likelihood that very little rich data could have been generated and could have provided little insight to the conceptual development of children in the foundation phase. Fortunately, the interview protocols provided ample opportunity for the participants to engage with science phenomena in a manner that is non-disruptive to the participants but importantly afforded them the opportunity to converse about science in their home language. These interview protocols contributed to a localised approach to knowledge generation. The design of the study further contributes to the methodology of translation in social science research by using a translator in a unique context. As discussed in Section 3.6 the translator's role was more than just a fieldworker, but his role extended further to that of a data source in itself as he became a research partner in the study allowing me to peer through a window to study the conceptual frameworks of the participants.

5.3.3 Contribution to primary school teacher education

This study also contributes to the practice of teacher education and informs possible policy changes to both foundation phase teacher education curricula as well as changes to the foundation phase school curriculum. Throughout this study I have referred to the current state of science education and science teacher education for the early grades. I argue for an integrated teacher education curriculum that employs science literacy as vehicle to train pre-service foundation phase teachers. I further argue that the foundation phase curriculum could benefit from the inclusion of more formalised science learning progressions (Wiser & Smith 2016) informed by research on children's theorising of the natural world.

5.6 LIMITATIONS OF THE STUDY

Although I argue for the internal validity of the study, with its detailed audit trail and explication and that it remained true to the construct, there is no argument for external validity, except, in the words of Eisner (1991, 2017) who said that the generalisation is in 'the eye of the beholder' (Eisner 2017). Readers of this study can transfer the findings to contexts that they know and for that the options remain open. The findings and conclusions drawn from the data is 'constrained' by the design of the *case* study - the inferences drawn from the data are only applicable to the parameters of the bounded system of the case which I presented . In Section 3.8 I argued that, for this study, construct validity and contextual validity would be the focal points to determine the trustworthiness of the findings and conclusions. The population from which the sample was drawn (randomly) was too small to allow any extrapolation of findings and conclusions to other contexts. This was, however, never the intention of the study as the aim was to gather rich data from the purposefully selected site that would inform my own practice as science teacher educator. This does not preclude the applicability of the findings and conclusions on other similar contexts as this study could be replicated in schools with similar parameters as the one studied in this research and in so doing increases the reliability of this study.

A further limitation of the collection and analysis of data lies in the disparity of language ability of the researcher. Not being fluent in isiZulu, limited my involvement during data collection and necessitated the use of translation to make the data accessible to myself. This could have caused the misinterpretation of data and skew the findings and inferences drawn from the findings. I mitigated against bias by being present in all data collection sessions, though. In Section 3.8 I discuss how the design of the study further mitigated this risk and limited the skewing of the findings and conclusions.

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5.7 RECOMMENDATIONS

I propose the following as potential outflows from this study:

5.7.1 A longitudinal study of children's science concept development

A longitudinal study, to track individual children's science concept development, should be undertaken to simply get to know what children in urban 'township' schools know and what the possible difference is for children growing up in rural villages or in middle class suburbia. I would recommend studies of other topics of early science learning. It would be valuable to know how such children's performance is throughout the primary school – including how they learn through medium of English. Similar protocols could be used.

Results from such longitudinal studies would inform the possible integration of curriculum subjects in teaching in the foundation phase by identifying curriculum themes from mathematics, language and life skills that could serve as crosscutting concepts (Erickson & Lanning 2014). Such a unit could be nested within a larger entity such as the South African Research Chair Initiative (SARchi) for the Integrated Studies of Learning Language, Mathematics and Science in the Primary School.

5.7.2 Development of science discourse for African languages

In Chapter 2 I discussed the importance of linguistic code in the learning and expression of concepts. There is currently limited capacity of research resources to allow for studies such as this one to be conducted on a larger scale. I recommend that more opportunities be generated that would allow for post-graduate programmes that could enable students to build capacity as researchers of science education in African languages.

5.7.3 Diagnostic investigation of children’s conceptual frameworks

The methods used in the study could be used by teachers in their own assessment practices. I recommend that science teachers and researchers of science education use and develop similar methodologies or protocols to diagnose the conceptual structures of children.

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5.7.4 Policy of the foundation phase curriculum

The composition of the foundation phase curriculum should be revised in order to incorporate the latest findings from international and national research on the learning of science concepts. These findings suggest domain specific learning trajectories and learning progressions that could scaffold the learning of science concepts. To achieve these policy changes would require greater collaboration between the department of higher education and training and the department of basic education to ensure alignment between the foundation phase teacher education curricula and the foundation phase curriculum. In-service teachers would also need to be trained given that most teachers did not receive adequate science training during their tertiary education.

5.8 CONCLUSION

Despite the gaps that arose during the progress of a study, I round off the thesis by glancing back at how I set out and conclude that the research journey has had ample yields. In Chapter 1 I argued that such a study is much needed, because teachers generally do not pay attention to the constructivist epistemologies that they purport to subscribe to. The South African school curriculum makes much of such an epistemology, yet, teachers do not, generally, live the tenets of constructivism. Finding out what children know, how they think, and how they model the natural world mentally, is crucial for teachers to teach with some fidelity. This study showed up some of children's understanding and how powerful beliefs and intuitive theories are. I argue that teachers should know this before they venture to 'add' knowledge to an unknown conceptual space.

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APPENDIX A: ETHICAL CLEARANCE UJ

NHREC Registration Number REC-110613-036

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ETHICS CLEARANCE

Dear F Naude

Ethical Clearance Number: 2016-009

Foundation Phase learners' concepts of the natural world.

Ethical clearance for this study is granted subject to the following conditions:

- If there are major revisions to the research proposal based on recommendations from the Faculty Higher Degrees Committee, a new application for ethical clearance must be submitted.
- If the research question changes significantly so as to alter the nature of the study, it remains the duty of the student to submit a new application.
- It remains the student's responsibility to ensure that all ethical forms and documents related to the research are kept in a safe and secure facility and are available on demand.
- Please quote the reference number above in all future communications and documents.

The Faculty of Education Research Ethics Committee has decided to

☒ Grant ethical clearance for the proposed research.
☐ Provisionally grant ethical clearance for the proposed research
☐ Recommend revision and resubmission of the ethical clearance documents

Sincerely,

Prof Geoffrey Lautenbach
Chair: FACULTY OF EDUCATION RESEARCH ETHICS COMMITTEE
15 April 2016

APPENDIX B: TRANSCRIPTS OF CLASSROOM SCIENCE DEMONSTRATIONS

Science Concept Project Transcripts

Grade R

00.01 Alright guys please tell me do you know what is science

00.13[pause] it's the sun

00.27 [silence] stop sign

00.28 discussion

1.19 do know what is an experiment?

1.21 Its spider man

1.22 batman

Astronomy

1.31 How do you know its morning?

1.32 good morning

1.33 good morning

Translation

2.05 The sun

2.08 What is the sun?

2.09 The sun.

2.31 It's the thing that lights for us to see.

2.40 The sun makes it to be warm when it is cold so that we can go to the street and play while it is hot.

3.12 Where is the sun?

3.17 Up

3.32 can you tell me what does the sun do?

3.40 It is hot

4.14 When our clothes a wet it makes them dry.

4.20 And shoes

4.33 when you have a sack and it is wet the sun comes and makes it dry.

4.45 When our clothes are dry we put them in the wardrobe.

5.09 how does the sun do it?

5.19 Very well

5.29 You have to wait for them to be dry.

5.40 After the dry you send a child to put them on the bed and fold them and the put them in wardrobe.

6.40 What happens to the sun at night?

6.48 It is not there.

6.56 Where does it go?

7.01 Home

7.02 goes to the sky.

7.13 What do you see in the sky when it is dark?

7.19 it’s dark.

7.20 What is in the sky when it’s dark?

7.32 there are stars.

7.36 moon

7.50 stars

8.01 What is the moon?

8.11 It’s a banana.

8.28 Where is the moon?

8.30 The moon up.

8.48 What does the moon do?

8.57 It shows you its night.

9.11 How does the moon show you its nighttime?

9.17 It shows you that it’s time to sleep.

9.45 Because it’s dark.

9.50 can you see the moon in the day?

9.52 No teacher.

10.03 What are stars?

10.12 star.

10.25 it’s human.

10.37 Where are the stars?

10.38 Up

10.45 is it the same place where the moon is?

10.54 No.

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10.58 What do stars do?

11.00 [trying to guess]

11.20 They shine

11.21 What happens to the stars in the day?

11.31 They go to the sky.

SHADOW experiment

11.44 What is this?

11.46 Light

12.02 What do you see?

12.05 hands

12.20 hand and light.

12.45 What do you see against the wall?

12.50 butterfly.

14.20 Do you know what is a shadow?

14.21 No

14.44 it a shade.

15.09 What do you see on the floor?

15.14 A human

15.52 do you have a shadow at night?

15.58 No

15.59 yes

16.00 yes

16.04 Why don't you have a shadow at night?

16.10 Because it is cold.

16.24 Because its night.

16.28 The thieves come.

16.38 Because it's dark.

LIVING AND NON-LIVING

16.51 Are you alive?

16.57 [pause] yes

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17.00 [whole class] we are alive

17.13 Why are you alive?

17.23 Because you are a human

17.30 What tells you that you are alive?

17.45 It is breathing.

18.03 breathing and walking.

18.53 you drink water.

18.59 is the water alive?

19.04 water is not alive

19.08 is alive we drink it.

19.13 [learner] why does it shake then?

19.30 Where can you find water?

19.39 From the tap.

19.49 From the mountain.

20.00 From the jug when you drink tea.

20.07 you collect water in the bucket.

20.11 From the kettle.

20.25 From the water car (truck)

20.34 What is this?

20.35 balloon.

21.45 tell me what is inside the balloon?

21.47 It is air.

22.09 is the air alive?

22.18 no/yes

23.34 What do you see?

23.38 A rock.

23.44 is the rock alive?

23.48 no/yes

24.22 Where else can you find rocks?

24.27 On the grass.

24.40 From the soil

24.46 From the mountains.

24.51 From the ground.

24.58 In the yard.

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25.01 What do you see in here?

27.16 It’s a seed

27.25 Where does the seed come from?

27.37 From the peach.

27.47 From the apple.

27.54 And down

27.55 An orange.

28.14 is the seed alive?

28.18 No.

28.25 Why do you say so?

28. 34 it does not walk.

28.51 What do you see?

28.52 A flower.

28.54 is the flower alive?

28.58 yes/no

29.00 yes

29.10 why?

29.22 Because it needs water.

29.27 Why does it need water?

29.28 To grow.

29.34 So a thing that grows is it alive or not.

29.35 It is alive

30.08 What do you see now?

30.11 A tree.

30.27 Where do trees come from?

30.33 From the soil.

30.36 From the grass.

30.43 is the tree alive?

30.47 yes/no

30.55 If you say no why do you say no?

31.02 Because it’s not talking.

31.09 Who says yes?

31.11 Why is it alive?

31.12 – 31.40 discussion

32.18 It is not alive.

32.22 what other trees do you know of?

32.33 The ones with the sticks.

32.40 peach trees

32.48 The ones for hiding.

32.54 For bombing.

33.15 What do you see?

33.16 bird.

33.20 Where does the bird come from?

33.27 comes from the sky.

33.34 is the bird alive.

33.38 yes.

33.39 Why do you say so?

34.58 Because it walks.

35.11 It flies

35.21 It can stand.

35.40 what other birds do you know of?

36.09 A black one

36.11 A brown one

36.14 A yellow one

36.15 An orange one

36.20 A colored one.

36.23 Where else can you find birds?

36.38 On the ground.

37.05 In town.

37.23 Who of you has a bird at home?

37.36 What birds do you have at home?

37.44 A bird.

37.56 dog

38.03 Where does the dog come from?

38.13 From the farm.

38.16 From the shop

38.20 Home.

38.29 From the zoo.

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38.38 From its cage.

38.51 is the dog alive?

38.57 yes

39.00 why?

39.07 Because its go.

39.18 Because it’s talking.

39.23 whoof-whoof!

39.36 what other dogs do you know of?

39.44 A puppy

39.52 A pit bull

39.57 bulldog.

40.05 police dog.

40.23 Where else can you find dogs?

40.37 Nowhere else.

40.52 From the shop

41.24 What is the difference between this [dog] and this [rock]?

42.22 Because the rock doesn't have teeth.

Experiments.

Balloon, baking powder and vinegar experiment.

44.45 If I put vinegar inside the baking powder, what is going to happen?

44.50 Its going to inflate.

44.56 why do think it’s going to blow?

44.59 [few learner] its air.

Pours vinegar inside the balloon with baking powder.

46.25 what did you see?

46.26 ball.

46.40 when you pour vinegar there is a white thing inside and it goes bhaaaa!

46.50 how many teaspoons of baking powder did we put into the balloon?

46.57 two

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47.01 we going to put five now.

47.53 what do you think is going to happen?

47.54 it’s gonna blow.

48.10 its going to inflate.

48.12 do you think its going to be big or small?

48.14 its going to be big.

48.15 why?

48.20 because he poured five things(spoons of baking powder)

48.21 pours five spoons of baking powder and vinegar.

49.49 which one is bigger

49.51 this one [learners pointing to bigger balloon]

49.53 why?

50.05 because he poured five teaspoons.

COMBUSTION

50.56 Is the flame alive?

51.05 yes.

51.10 why?

51.12 silence

51.16 [mumblings]

52.20 what is going to [to the flame] happen if I put vinegar in there?

52.27 its gonna phh..!

52.37 its going to be big.

52.41 its going to be put out.

52.47 why?

52.52 because he poured water.

52.55 I’m not going to pour the vinegar onto the flame, do you still it’s going to go off?

53.08 [class] no!

53.16 its going to be big[the flame].

54.28 what happened to the flame?

54.29 Its gone.

54.35 why is the flame gone?

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54.37 [silence]

54.48 because he poured baking powder and vinegar.

ABSORPTION

58.25 MARKS THE WATER LEVEL.

58.38 What is going to happen if I put this [kitchen paper towel] in there?

58.40 [silence]

58.53 it's going to be white. [Water]

59.40 puts the paper towel inside the water.

59.50 what happened?

1.00.05 its pink.

1.00.10 the tissue changed the colour to pink.

1.00.18 what happened to the water?

1.00.34 the water went down/reduced.

1.00.46 what happened?

1.00.47 [silence]

You put the tissue inside the water and it turned red

1.02.21 we are using five tissue paper now.

1.02.44 what is going to happen if I put all five in there?

1.02.58 they are going to turn pink.

1.03.13 the water is going to go down.

1.03.28 dips the paper towel into the water.

1.03.46 what did you see?

1.04.03 they put the tissue inside the water and it turned pink.

1.04.12 it reduced the water.

1.04.26 which one took most of the water?

1.04.50 the one with five pieces.

1.04.52 why?

1.05.05 because it had a lot of papers.

PROPULSION

1.08.35 What is going to happen if I leave the balloon?

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1.08.42 it is going to go.

1.08.45 why?

1.08.46 its gonna go with the straw.

1.08.52 if I leave the balloon which way is the air going to come out?

1.09.20 that side [pointing on the side of the opening]

1.11.30 what did you see?

1.11.38 I saw the balloon moving.

1.12.   Why did it move.

1.12.21 because you inflated it and let it go.

<u>Grade 3: Transcription</u>

Introduction

Question: (00:21)	Do you know what science is?
Answer 1: (00:22)	No!!!!(*Majority of the learners shout out)*
Question: (00: 25)	Don't you?
Answer: 1: (00:26)	Yes!! (*Majority of the learners shout out)*
Question: (00:28)	So you don't even have the slightest idea? Who wants to take a guess?
Answer 1: (00:36)	Magic (*Girl)*
Question: (00:41)	Why do you say its magic?
Question: (00:50)	What is magic?
Question: (00:58)	Is it a difficult question to answer?
Question: (01:03)	Do you know what an experiment is?
Answer 1: (01:05)	No!!! (*majority of the learners shout out*)
Question: (01:27)	How do you know it is morning?
Answer1: (01:32)	You see with light (girl)
Answer 2: (01:36)	I see outside, when it is white outside.(boy)
Answer 3: (01:44)	and the sun *(Girl)*
Question: (01:49)	Tell me, what is the sun?
Answer 1: (02:00)	Fire *(Girl)*
Question: (02:04)	Is the sun fire? Who else wants to tell me what is fire?
Answer 1: (02:06)	Light *(Boy)*
Answer 2: (02:14)	It's a good fire *(Boy)*
Question: (02:18)	Where is the sun , tell me where is the sun?

Answer 1: (02:24)	It's up *(Boy)*
Answer 2: (02:27)	It's in the sky (*Boy)*
Answer 3: (02:29)	It's in out of space (Boy)
Answer 4: (02:33)	Up in the sky *(Girl)*
Question: (02:36)	What is space if you say it's in out of space?
Answer 1: (02:39)	A planet *(Boy)*
Questions: (02:43)	Where are planets?
Answer 1: (02:50)	In the garden *(Boy)*
Question: (02:53)	Not plants but planets?
Answer 1: (02:57)	Is a moon *(Girl)*
Question: (03:05)	What happens to the sun when it's night?
Answer 1: (03:08)	It goes up to the sky *(Girl)*
Answer 2: (03:24)	It go under the moon (*Boy)*
Answer 3: (03:31)	The clouds close the sun
Answer 4: (03:38)	The clouds close the sun and the moon *(Boy)*
Answer 5: (03:42)	The planets rounds *(Boy)*
Answer 6 (03:51)	The sun hides and it becomes dark(*Girl)*
Question: (03:56)	And what do you see when it becomes dark?
Answer 1: (04:00)	You see clouds *(Boy)*
Answer 2: (04:04)	You see stars *(Girl)*
Answer 3: (04:06)	Moons (*Girl)*
Answer 4: (04:12)	Clouds *(Girl)*
Answer 5 (04:15)	I see lights (Boy)
Question: (04: 17)	What lights do you see?
Answer 1: (04:22)	White lights (*Boy)*
Answer 2; (04:28)	I see blue sky (*Boy)*
Answer 3: (04 :33)	White moon (*Girl)*
Answer 4: (04:39)	Half-moon (*Boy)*
Question: (04:42)	What is the moon?
Answer 1 (04:47)	It's a planet *(Boy)*
Question: (04:50)	What shape is the moon?
Answer1: (04:55)	Is like a banana *(Girl)*
Answer 2: (05:04)	Is a circle *(Boy)*
Answer 3: (05:07)	It gets circle when it is morning (*Girl)*
Answer 4: (05:12)	Sometimes its whole *(Girl)*
Question: (05:21)	And stars what are stars?
Answer 1: (05:26)	White (Girl)

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Question: (05:33)	Does anybody else want to tell me what are stars?

There is a long silence in the classroom

Question: (05:49)	Ok let me ask you this, Is the sun a star?
Answer 1: (05:50)	Some learners shout out No!! and others Yes!!
Question: (05:56)	Who says yes the sun is a star? Lift up your hand.
Answer 1: (06:01)	One learner raises her hand.
Question: (06:02)	Why do you say so?
Answer 1: (06:03)	Because its bright like a star.
Question: (06:06)	Who says no the sun is not a star?
Answer 1: (06:12)	Because star is white and sun is yellow *(Girl)*
Answer 2: (06:18)	The sun is big and the star is small *(Boy)*
Answer 3: (06:26)	The sun is circle and the stars are ……. *(Girl)*
Question: (06:33)	What shapes are stars?
Answer1: (06:40)	Star *(Girl)*
Answer2: (06:44)	The sun is bright and the moon is not bright. *(Boy)*
Answer 3: (06:53)	The star come at night and the sun don't come at night *(Girl)*
Answer 4: (07:01)	The star is a rectangle *(Boy)*
Question: (07:07)	Do you agree?, What shape are stars?
Answer1: (07:09)	Star (Majority *of the learners shout out*)
Question: (07:16)	What happens to the moon when it is day?
Answer 1: (07:32)	It becomes half *(Girl)*
Question: (07:33)	Anybody else who wants to tell me what happens to the moon at night
Answer 2: (07:44)	It comes out *(Girl)*
Question: (07:46)	Can you see the moon when it is day?
Answer1: (07:48)	No!! (Some *learners shout out)*
Answer 2: (*07:5*0)	The sun comes out *(Boy)*

Shadow demonstration

Question: (07:58)	Do you know what is this? (Mr Naude holding a Torch in his right hand)
Answer 1: (08:00)	Yes (*The majority of the class shouts out)*
Answer 2: (08:01)	Torch *(Few learners shout out)*
Question: (08:02)	What's the nice English word ?
Answer 1: (08:04)	Flashlight (*Few learners shout out)*
Question: (08:07)	What does the flashlight do ?
Answer 1: (08:09)	You use it when its night *(Boy)*

Answer 2: (08:15)	If you want to take something when its dark you take a flashlight (*Girl)*
Answer 3: (08:21)	If you go to the camp and the dark *(Boy)*
Answer 4: (08:33)	When outside it is dark you use a torch *(Boy)*
Answer 5: (08:40)	When you want your phone you light a torch (*Girl)*

Mr Naude reflects the flashlight on a piece of kitchen paper.

Question: (09:07)	What do you see?
Answer 1: (09:11)	A tissue and a flashlight *(Boy)*
Answer 2: (09:26)	I see a light *(Boy)*
Answer 3: (09:31)	I see a bright light *(Boy)*
Question: (09:36)	What is going to happen if a put my hand in the way of the light?
Answer 1: (09:41)	The light will go*….. (Boy)*
Answer 2: (09:50)	The light will be on your hand *(Boy)*
Answer 3: (09:55)	It's going to be dark (*Girl)*
Question: (09:58)	What is going to be dark?
Answer 1: (10:07)	It's going to be dark when you put your hand *(Girl)*
Answer 2: (10:13)	Your hand will be light (*Girl)*
Answer 3: (10:17)	Your hand will be like a flashlight *(Boy)*
Answer 4: (10:24)	Your hand will be light (*Girl)*

Mr Nauda puts his hand in front of the flashlight as it is reflected on the kitchen paper.

Question:(10:27)	What do you see?
Answer 1: (10:30)	We see your hand *(Boy)*
Question: (10:31)	Where do you see my hand?
Answer 1: (10:33)	On the toilet paper *(Boy)*
Answer2: (10:37)	I see the shadow of your hand *(Boy)*
Answer 3: (10:46)	I see a flashlight in your hand (*Boy)*
Question: (10:47)	What colour is my hand ?
Answer 1: (10:48)	White (*Boy)*
Question: (10:51)	What colour is the hand on the tissue?
Answer 1: (10:53)	Black!! (Majority of the learners shout out)
Question: (10:55)	Why is my hand white and the shadow is black?
Answer 1: (11:01)	Because your hand is a ……. *(Boy)*
Answer 2: (11:14)	Because your hand is a shade (*Girl)*
Question :(11:18)	What is a shadow?
Answer1: (11:29)	A shadow is a thing that is black when you move it follows you. (Boy)
Question: (11:40)	Do all of you have shadows?

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Answer1: (11:41)	Yes!!!! (*The majority of the learners shout out)*
Question: (11:43)	When do you have a shadow?
Answer 1: (11:47)	In the afternoon (Girl)
Answer 2: (11:50)	When the sun is bright *(Boy)*
Question: (11:55)	Do you have a shadow at night?
Answer 1: (11:56)	Nooo!! (*The majority of the learners shout out)*
Question: (12:00)	Why don't you have a shadow at night?
Answer 1: (12:03)	Because it is dark (*Girl)*
Answer 2: (12:07)	Because when outside its dark you can't see *(Boy)*

<u>Section 2: Living and Non-living</u>

Question: (12:25)	Are you alive?
Answer 1: (12:26)	Yes (*The majority of the learners shout out)*
Question: (12: 29)	How do you know you alive?
Answer 1: (12:33)	We can speak *(Girl)*
Answer 2: (12:34)	We can walk *(Girl)*
Answer 3: (12:37)	We can breath (*Girl)*
Answer 4: (12:43)	We can eat *(Girl)*
Answer 5: (12:45)	We can speak a lot (*Girl)*
Answer 6: (12:49)	We can touch (*Girl)*
Answer 7: (12:54)	We can talk to a human *(Boy)*
Answer 8: (13:00)	We can drink (*Boy)*
Answer 9: (13:01)	We can wash *(Girl)*
Answer 10: (13:03)	We can run *(Boy)*
Answer 11: (13:05)	We can sit (*Girl)*
Answer 12: (13:07)	We can drive (*Boy)*
Answer 13: (13:10)	We can exercise (Girl)
Answer 14: (13:14)	You can kick (Boy)
Answer 15: (13:16)	You can stretch *(Boy)*
Answer 16: (13:19)	You can tie your shoes (Girl)
Answer 17: (13:22)	You can walk *(Boy)*
Answer 18: (13:24)	You can gym *(Boy)*
Answer 19: (13:27)	You can speak (*Girl)*
Answer 20: (13:29)	You can sleep *(Girl)*
Answer 21: (13:31)	You can smile (Girl)

Mr Naude pours water into a small plastic cup

Question: (13:47)	What do you see?
Answer1: (13:50)	I see water (*Girl)*

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Answer 2: (13:55)	I see water in a bottle (*Boy)*
Answer 3: (14:03)	I see a plastic cup inside you put a water (Boy)
Question: (14:18)	Is water alive?
Answer 1: (14:20)	No!!!/ Yes!! (Learners *shout out)*
Question: (14:24)	Put up your hand if you say water is alive?
Answer 1: (14:25)	One learner raises his hand
Question: (14:36)	Why do you say water is not alive ?
Answer 1: (14:39)	Because water is not alive like you (Boy)
Answer 2: (14:45)	Water is not like you the same(*Boy)*
Answer 3: (14:50)	Water don't have bones *(Girl)*
Answer 4: (15:00)	The water can't walk *(Girl)*
Answer 5: (15:03)	You can't speak with water *(Boy*
Answer 6: (15:07)	The water doesn't have legs (Girl)
Answer 7: (15:14)	Water can breath (Girl)
Answer 8: (15:17)	No hands (*Girl*)
Answer 9: (15:19)	Water don't have a mouth *(Girl)*
Answer 10: (15:24)	Doesn't have a face (*Boy)*
Answer 11: (15:28)	Doesn't have legs (Boy)
Question: (15:30)	What can you do with water?
Answer 1: (15:33)	Drink water (*Girl)*
Answer 2: (15:36)	You can wash yourself (Boy)
Answer 3: (15:39)	You can bath *(Girl)*
Answer 4: (15:41)	You can cook (Girl)
Answer 5: (15:44)	You can drink (*Boy)*
Answer 6: (15:47)	You can make a plant *(Girl)*
Answer 7: (15:50)	You can wash your car *(Girl)*

Mr Naude shows the learners a balloon

Question: (16:08)	What is this?
Answer 1: (16:11)	A balloon (*Majority of the class shouts out)*
Answer 2: (16:20)	Blue *(Boy)*
Question: (16:22)	What is inside the balloon?
Answer 1: (16:24)	Nothing (*Boy)*
Answer 2: (16:26)	Water (*Girl)*
Question: (16:30)	And if I do this what is inside the balloon?
Answer 1: (16:33)	Nothing (*Majority of the class shouts out)*

Mr Naude blows the balloon

Question: (16:49)	And now what is in the balloon?

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Answer 1: (16:51)	Air (Boy)
Question: (16:55)	Are you sure?
Answer 1: (16:56)	Yes (Boy)
Question: (16:57)	How do you know there is air inside?
Answer1: (17:00)	Because you blow it *(Boy)*
Question: (17:03)	What's going to happen if I let go? *Referring to the balloon*
Answer 1: (17:06)	There will be no air (*Boy)*
Answer 2: (17:09)	It's going to fly (*Girl)*

Mr Naude lets go of the balloon

Question: (17:28)	So you said inside the balloon there is air where else can you get air?
Answer1: (17:34)	You can find air outside (*Boy)*
Answer 2: (17:40)	In the house when we open the windows (*Girl)*
Answer 3: (17:43)	On the shop (*Boy)*
Answer 4: (17:47)	In the world (Girl)
Question: (17:51)	Is there air inside the class?
Answer 1: (17:54)	No!!!/ Yes!!! (*Learners shout out)*
Answer 2: (17:57)	When we open the windows (*Boy)*
Question: (17:59)	When the door is open?
Answer 1: (18:02)	Yes *(Majority of the learners shout out)*
Question: (18:04)	What can you do with air?
Answer 1: (18:08)	You can't do anything (*Boy)*
Answer 2: (18:10)	You can breath (*Girl)*
Question: (18:14)	Is air alive?
Answer 1: (18:16)	No (*Majority of the learners shout out)*
Question: (18:17)	Why do you say so?
Answer 1: (18:19)	Because you don't see air *(Boy)*
Question: (18:25)	Why not?, why is air not alive?
Answer 1: (18:28)	Because you can't touch it (*Girl)*
Answer 2: (18:31)	Because you can't hold it *(Boy)*
Answer3: (18:34)	You can't hug it *(Girl)*
Answer4: (18:36)	Because you can't speak to it (*Boy)*

Mr Naude shows them a rock

Question: (18:46)	What do you see?
Answer 1: (18:56)	Stone (*Boy)*
Answer 2: (19:00)	A rocks (*Boy)*
Question: (19:09)	Is the rock alive?

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Answer1: (19:11)	No!!! (*Majority of the learners shout out)*
Question: (19:12)	Why do you say so?
Answer 1: (19:15)	You can't speak to it (*Boy)*
Answer 2: (19:17)	You can't build with it (Boy)
Question: (19:28)	Can you or can't you build with it?
Answer 1: (19:32)	Yes (*Majority of the learners shout out)*
Answer 2: (19:35)	It can't walk (*Girl)*
Answer 3: (19:37)	It don't have bones (*Girl)*
Answer 4: (19:39)	It can't see (*Girl)*
Answer 5: (19:43)	It can't bath (Girl)
Answer 6: (19:49)	It can't talk (*Girl)*
Answer 7: (19:51)	It don't have legs (*Girl)*

Mr Naude shows them seeds

Question: (20:02)	What do you see?
Answer1: (20:06)	The beads of a flower (*Boy)*
Question*: (20:16)*	So you say they are beads of a flower what do you call that?
Answer 1: (20:19)	Seeds (*Boy)*
Question: (20:22)	What are seeds?
Answer 1: (20:28)	From the flower (*Boy)*
Question: (20:31)	What do seeds do?
Answer 1: (20:35)	Seeds plant things (*Girl)*
Question: (20:42)	What happens to seeds when we plant them?
Answer1: (20:44)	Seeds plant flowers (*Boy)*
Answer 2: (20:51)	Seeds grow up flowers (*Girl)*
Answer 3: (20:57)	It can grow (*Boy)*
Answer4: (21:00)	You can plant it *(Boy)*
Question: (21:03)	Are seeds alive?
Answer 1: (21:04)	No!!! (*Majority of the learners shout out)*
Question: (21:09)	You say no, why do say no the seeds are not alive?
Answer 1: (21:14)	The seeds can't walk (*Boy)*
Answer 2: (21:18)	It can't breathe (*Girl)*
Answer 3: (21:20)	It can't see (*Girl)*
Answer 4: (21:24)	It can't talk *(Boy)*
Answer 5: (21:27)	It can't eat *(Girl)*
Answer 6: (21:29)	It can't drink water (*Girl)*
Question: (21:34)	Why do we give seeds water?
Answer 1: (21:37)	Because they need to grow (*Girl)*

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Answer 2: (21:44)	To be bigger (*Boy)*
Answer 3: (21:50)	Sunlight (Girl)
Question: (21:53)	Why do they need sunlight?
Answer1: (21:58)	They need sunlight to grow *Girl)*
Answer2: (22:03)	And rain *(Girl)*
Question: (22:10)	You said that seeds grow, do you grow?
Answer1: (22:12)	Yes!!! *(The whole class shouts out)*
Question: (22:15)	Do you grow?
Answer 1: (22:17)	Yes!!! (*The whole class shouts out)*
Question: (22:27)	Are you alive?
Answer 1: (22:28)	Yes!!! (The whole class shouts out)
Question: (22:30)	Does the seed grow?
Answer1: (22:31)	Yes!!! (*The whole class shouts out)*
Question: (22:32)	Is the seed alive?
Answer1: (22:34)	Nooo!! *(The whole class shouts out)*

Mr Naude shows the learners a pot plant

Question: (22:42)	What is this?
Answer 1: (22:44)	Flowers *(Girl)*
Question: (22:48)	What can you do with flowers?
Answer 1: (22:54)	You can take them and then you give your friend *(Girl)*
Question: (22:59)	Why do you want to give flowers to your friend?
Answer1: (23:03)	Because it's her birthday (*Girl)*
Answer 2: (23:09)	You can plant your flowers in your house.(*Boy)*
Answer 3: (23:15)	You can talk to your flowers (*Boy)*
Question: (23:17)	You can talk to the flowers, are they going to listen?
Answer1: (23:19)	Nooo!! (*The whole class shouts out)*
Answer 2: (23:22)	You can give flowers to your friend because you love her. *(Girl)*
Answer 3: (23:30)	You can decorate inside your house. *(Girl)*
Question: (23:33)	Is the flower alive?
Answer 1: (23:34)	Nooo!! (The whole class shouts out)
Question: (23:36)	Why do you say so?
Answer 1: (23:38)	It can't listen (*Boy)*
Answer 2: (23:40)	It can't breathe *(Girl)*
Answer1: (23:43)	Because it can't talk *(Boy)*
Answer2: (23:45)	Because it can't walk *(Boy)*
Answer3: (23:48)	Because it can't speak (*Girl*)
Answer4: (23:50)	Because it can't drink *(Boy)*

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Answer 5: (23:55) Because it can’t see (*Girl)*

Answer 6: (23:57) Because it can’t speak (*Girl)*

Answer 7: (23:59) Because it can’t dance *(Girl)*

Question: (24:02) Why do we give flowers water?

Answer 1: (24:08) We give flowers water to grow. *(Boy)*

Answer 2: (24:13) To make fruits. *(Girl)*

Question: (24:21) So you say that flowers grow?

Answer1: (24:22) Yes!!! (*The whole class shouts out)*

Question: (24:23) And you, do you grow?

Answer1: (24:24) Yes!!! (*The whole class shouts out)*

Question: (24:25) Of course you said that, are you alive?

Answer 1: (24:26) Yes!!! (*The whole class shouts out)*

Question: (24:28) Are flowers alive?

Answer 1: (24:29) Nooo!! (*The whole class shouts out)*

Mr Naude cuts a flower from the pot plant

Question: (24:43) What happened?

Answer1: (24:50 The flower could never grow. (*Boy)*

Question: (24:54) Why won’t it grow?

Answer1: (24:57) Because you cut it. (*Boy)*

Answer2: (25:03) Because the flower will*……(Boy)*

Answer 3: (25:16) It can’t grow again because you cut it.*(Girl)*

Answer4: (25:22) The flower never grow again. *(Girl)*

Question: (25:27) Is this flower alive?

Answer1: (25:29) Nooo!! (*The whole class shouts out)*

Mr Naude shows the learners a tree

Question: (25:37) What is this?

Answer1: (25:41) Is a tree (*Boy)*

Answer 2: (25:47) It’s a tree (*Boy*)

Answer3: (25:49) It’s a small tree *(Boy*)

Answer4: (25:50) It’s a garden (Boy)

Question: (25:55) Is the tree alive?

Answer1: (25:57) No!!!!/Yes!!!! (*The learners shout out)*

Question: (26:01) Why do you say yes?

Answer1: (26:16) Because it grows apples. (*Boy)*

Answer 2: (26:24) Me I say no because a tree you can’t talk to it (*Boy)*

Answer3: (26:35) I say no because the tree can’t listen (*Girl)*

Question: (26:41) Who says the tree is not alive?

Question: (26:44)	Why do you say the tree is not alive?
Answer1: (26:47)	Because it don't have feet. (*Girl)*
Answer 2: (26:52)	You can't talk with it *(Boy)*
Answer 3: (26:57)	I say yes because the tree can move *(Girl)*
Question: (27:04)	How does the tree move?
Answer1: (27:07)	When the air is more (Boy)
Answer2: (27:14)	When there's windy (*Girl)*

Mr Naude show the learners a bird

Question: (27:57)	What do you see?
Answer1: (28:00)	I see a bird. (*Boy)*
Answer 2: (28:03)	I see wings *(Girl)*
Answer3: (28:11)	I see a bird (*Boy)*
Answer4: (28:15)	I see different colours *(Girl)*
Answer5: (28:18)	I see a cage of a bird *(Girl)*
Answer6: (28:20)	Eyes (Boy)
Question: (28:23)	Do you hear anything?
Answer1: (28:25)	Yes!! *(Majority of the learners shout out)*
Question: (28:27)	What do you hear?
Answer1: (28:31)	I hear a bird sound *(Boy)*
Answer2: (28:35)	I hear a noise (*Boy)*
Answer3: (28:39)	I hear a bird sound (*Girl makes a bird sound)*
Question: (28:40)	Is the bird alive?
Answer1: (28:42)	Yes!! (*Majority of the learners shout out)*
Question: (28:43)	Why do you say so?
Answer1: (28:47)	It has a heart. *(Girl)*
Answer2: (28:50)	It has eyes (*Boy)*
Answer 3: (28:52)	Because it can eat *(Girl)*
Answer4: (28:57)	It can breathe *(Girl)*
Answer5: (29:00)	He can make his own house (Boy)
Answer6: (29:07)	He can jump and move (Girl)
Answer7: (29:10)	It can sing (Girl)
Answer8: (29:15)	It can fly (Boy)
Question: (29:20)	Who's got birds at home?

Long silence from the learners

Question: (29:28)	Do your parents have birds at home?
Answer1: (29:31)	Nooo!! (*The whole class shouts out)*

Mr Naude shows the learners a picture of a dog

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Question: (29:45)	What do you see?
Answer1: (29:47)	Dog *(Boy)*
Answer2: (29:50)	Picture of a dog *(Girl)*
Answer3: (29:59)	I see different colours on a dog *(Girl)*
Question: (30:04)	Do you have a dog at home?
Answer1: (30:06)	Yes!! (*Majority of the learners shout out)*
Question: (30:07)	What type of dogs do you have at home?
Answer1: (30:10)	Rodviders ooooooo
Answer2: (30:14)	Snoopy *(Girl)*
Answer3: (30:19)	Pit bulls *(Boy)*
Answer4: (30:24)	Scratch *(Boy)*
Answer5: (30:27)	Puppies *(Girl)*
Answer6: (30:31)	China dog (*Girl)*
Answer7: (30:33)	Smocky *(Girl)*
Question: (30:36)	Tell me is your dog alive?
Answer1: (30:40)	Yes!! (*Majority of the learners shout out)*
Question: (30:41)	Why do you say so?
Answer1: (30:44)	Because it can breathe *(Boy)*
Answer2: (30:48)	It can drink (*Girl)*
Answer3: (30:52)	It can make babies (*Boy)*
Answer4: (30:57)	It can eat *(Boy)*
Answer5: (30:59)	It can run (*Boy)*
Answer6: (31:01)	It has bones (*Girl)*
Answer7: (31:03)	You can talk with your dog *(Boy)*
Answer8: (31:08)	It has teeth and mouth (Boy)
Answer9: (31:20)	It can run (*Girl)*
Answer10: (31:22)	You can tell your dog what to do (*Boy)*
Answer11 :(31:25)	It can bite (*Girl)*
Answer12: (31:28)	You can train it (*Girl)*
Answer13: (31:31)	You can take your dog a walk *(Boy)*

Section 3: Chemistry

Demonstration: the reaction between vinegar and backing powder

Mr Naude shows the learners white powder that he has put on the tea-spoon

Question: (32:07)	Do you know what this powder is?
Answer1: (32:10)	Bicarbonate (*Girl)*
Question: (32:15)	What is bicarbonate of soda?
Answer1: (32:20)	Something like a sweet aid (Girl)

Answer2: (32:27)	You can make a volcano *(Boy)*
Answer3: (32:32)	You can cook (*Boy)*
Answer 4: (32:35)	You can make sherbet *(Girl)*
Answer 5: (32:39)	You can make a bomb *(Boy)*
Answer 6: (32:40)	It's something that is salt (*Girl)*
Answer 7: (32:49)	When the balloon is soft you going to put bicarbonate of soda) and….(Boy)
Question: (32:59)	How do you know?

Long silence from the learners

Question: (33:05)	You said you can use it to do a volcano, how can you do a volcano?
Answer1: (33:13)	You can take a stean (rock) and then you tie the stean to a balloon. *(Boy)*

Mr Naude pours the bicarbonate of soda into the balloon using teaspoon. (1 teaspoon)

Question: (33:45)	What is inside the balloon now?
Answer1: (33:48)	Bicarbonate of soda (*All the learners shout out)*
Question: (33:52)	What do I have here?
Answer1: (33:53)	Vinegar *(All the learners shout out)*
Answer2: (33:55)	Water *(Girl)*
Question: (34:03)	What can you do with vinegar?
Answer1: (34:07)	You can make beetroot (Girl)
Answer2: (34:13)	You can eat with chips (Boy)
Answer3: (34:24)	If your stomach is sore you can drink it with water (*Girl)*
Question: (35:01)	What is going to happen if I put vinegar in the balloon?
Answer1: (35:05)	Is going to be warm (*Boy)*
Answer2: (35:14)	Inside the balloon it will be lot of steam. (*Girl)*
Answer3: (35:20)	Is going to blow *(Girl)*
Answer4: (35:27)	To fly *(Girl)*

Mr Naude puts the vinegar inside the balloon using a searing

Question: (36:12)	What is happening?
Answer 1: (36:15)	Is blowing up (*Girl)*
Question: (36:20)	Why is it blowing up?
Answer1: (36:24)	Because you put water (Boy)
Answer2: (36:38)	Because you put vinegar and bicarbonate of soda (Boy)
Question: (36:49)	What is happening inside the balloon?
Answer1: (36:55)	It's mixing *(Boy)*
Question: (36:59)	Who said that the balloon is going to become warm?

Answer1: (37:03)	***Learner raises his hand***
Question: (37:04)	Do you want to feel it?
Answer1: (37:05)	Yes (***The boy stands up to feel the balloon)***
Question: (37:10)	Is it warm?
Answer: (37:11)	No (*Boy nods his head)*
Question: (37:13)	What is it?
Answer1: (37:14)	Cold *(Boy)*
Question: (37:15)	Why is it cold?
Answer1: (37:19)	Because the vinegar is cold *(Boy*)

Mr Naude does the same experiment using another balloon and more bicarbonate soda. 5 teaspoons

Question: (38:07)	What's going to happen if I put vinegar?
Answer1: (38:11)	Its goner blow it when you put .(Boy)
Answer2: (38:23)	Its goner bomb (*Girl)*
Answer 3 (38:36)	Is going to say boom *(Girl)*
Question: (38:42)	What do you think is going to happen?
Answer1: (38:45)	Is going to sheeeeeeessh (*The boy makes a sound)*
Answer2: (38:55)	The vinegar is going to blow the balloon (Boy)
Question: (38:58)	Is it going to be as big as this one comparing it to the previous balloon.
Answer1: (38:59)	Noooo!!! (*All the learners shout out)*
Answer 1: (39:08)	Is going to be bigger than this one (*Boy)*

Mr Naude puts the vinegar inside the balloon using a searing

Question: (40:27)	What is happening?
Answer 1: (40:28)	I hear a sound *(Boy)*
Question: (40:29)	Why do you hear that?
Answer1: (40:37)	Because you are shacking it *(Boy)*
Answer2: (40:40)	Because you added water/vinegar *(Boy)*
Question: (40:47)	If I shack this one (referring to the first balloon) what do you hear?
Answer1: (40:52)	Nothing *(All the learners shout out)*
Question: (40:54)	Why?
Answer1: (41:00)	Because that one is small (*Boy)*
Answer2: (41:06)	Many vinegar *(Boy)*

Mr Naude does the same experiment using another balloon and more bicarbonate soda. 5 teaspoons and more vinegar

Question: (42:26)	What happened?

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Answer1: (42:32) This one is big and this one is small *(Boy)*

Answer2: (42:37) This balloon is bigger than this one and this balloon is smaller than this one (*Girl)*

Answer3: (42:44) This balloon is bright (*Boy)*

Answer4: (42:49) This one you didn't put 5 teaspoons of bicarbonate soda and this one you did put 5 teaspoons

Question: (43:01) So this one is bigger than this one? (referring to the first and last balloon)

Answer1: (43:03) Yes *(All the learners shout out)*

Mr Naude uses a vas with a candle inside for his next experiment

Question: (43:15) What do you see?

Answer1: (43:17) I see a candle with a matches (*Boy)*

Answer 2: (43:22) I see a candle inside a bottle *(Girl)*

He puts 6 teaspoons of bicarbonate soda at the bottom of the vas and lights the candle.

Question: (45:25) If I put vinegar at the bottom of the vas without it touching the flame what is going to happen?

Answer1: (45:40) The bicarbonate of soda will be…..(*Boy)*

Answer 2: (45:50) The bicarbonate will boom (Boy)

Question: (46:00) So is there going to be big flame?

Answer1: (46:03) Yes!!!/No!!! (*Learners shout out)*

<u>Video 2</u>

Answer 3: (00:02) The candle will go down (*Boy)*

Answer4: (00:09) The candle is going to be small (*Girl)*

Question: (00:16) Do you want to see what happens?

Answer1: (00:17) Yes *(All the learners shout out)*

Question: (00:18) Do you think you going to hear anything?

Answer1: (00:20) Yes (*All the learners shout out)*

Question: (00:*22)* What are you going to hear?

Answer1: (00:23) SHSSSSSSSSHHHH (*All the learners make that sound)*

After he puts the vinegar in the vas

Question: (00:51) What happened?

Answer1: (00:55) The vinegar shut down the flame (*Girl)*

Answer2: (01:07) Is like Eno *(Girl)*

Answer3: (01:10) Is like magic *(Boy)*

Answer4: (01:14) The light disappeared *(Girl)*

Question: (01:19) Why did the flame go out?

Answer1: (01:23) Because the steam went up and it start to go off *(Girl)*

Answer2: (01:39)	Because the matches don't like water (*Boy)*
Answer3: (01:46)	Because the steam go up and the candle disappeared (*Boy)*

<u>Video 3:</u>

Absorption experiment

Mr Naude pours water into a measuring cylinder

Question: (00:01)	What color is the water?
Answer1: (00:04)	Green (*Boy)*
Answer2: (00:07)	Cream (*Boy)*
Answer3: (00:09)	Silver (*Boy)*
Answer5: (00:11)	White *(Boy)*
Question: (00:14)	What do I have here? (*Referring to a bottle of food coloring)*
Answer1: (00:20)	You have a baking, when you bake you bake with that (Girl)
Answer2: (00:33)	Food coloring (*Boy)*
Question: (00:36)	Is it food coloring, what does food colouring do?
Answer1: (00:39)	We put it in veggies (*Boy*
Answer2: (00:48)	It makes water dye *(Girl)*
Answer3: (00:49)	It changes the water colour *(Boy)*
Question: (00:55)	So if I put this in here what is going to happen?
Answer1: (00:58)	The water will be red (*Girl)*
Question: (01:01)	How quickly will the water become red?
Answer1: (01:05)	When you are shaking it (*Boy)*

Mr Naude pours the food colouring into the cylinder with water

Question: (01:29)	What is happening?
Answer1: (01:34)	The waters colour is changing (*Boy)*
Answer2: (01:36)	The water is getting red (*Girl)*
Answer3: (01:40)	The food colouring is going down *(Girl)*

Mr Naude uses a green marker to indicate the measurement of the water

Question: (02:00)	What does this line mean
Answer1: (02:04)	It is where the water starts *(Boy)*
Question: (02:17)	What do I have here?
Answer1: (02:18)	Toilet paper *(Majority of the learners shout out)*
Question: (02:31)	Is this a big piece or a small piece?
Answer1: (02:33)	Small piece (*Majority of the learners shout out)*
Question: (02:35)	What colour is the toilet paper?
Answer1: (02:38)	White *(Majority of the learners shout out)*
Question: (02:47)	What is going to happen if I put the toilet paper in the water?
Answer1 :(02:55)	The water is going to be white and red *(Boy)*

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Answer2: (03:02)	The toilet paper will be red *(Girl)*
Answer3 :(03:08)	There will be white paper *(Boy)*
Question: (03:12)	What else is going to happen?
Answer1: (03: 20)	The toilet paper is going to be red (*Girl)*
Question: (03:31)	How long should we keep it in the water?
Answer1: (03:36)	5 seconds *(Girl)*

After he puts the toilet paper in the water

Question: (03:50)	What happened?
Answer1: (03:54)	The tissue is red *(Boy)*
Question: (03:58)	*What else?*
Answer1: (04:02)	The toilet paper is *(Long pause from the girl)*
Answer2: (04:16)	The water squash the toilet paper (*Boy)*
Answer3: (04:21)	The toilet paper is like chicken skin *(Girl)*
Question: (04:27)	Why is it like a chicken skin?
Answer1: (04:33)	Because it has small things (*Girl)*

Mr Naude uses a red marker to indicate the measurement of the water after putting the tissue

Question: (04:51)	What does that red line say?
Answer1: (04:56)	There is something red in the plastic bottle (*Girl)*
Question: (05:03)	Where was the water when we started?
Answer1: (05:08)	On the red line (Boy)
Answer2: (05:11)	On the red line (*Boy)*
Question: (05:14)	So where is the water now?
Answer1: (05:17)	On the red line (*Girl)*
Question: (05:19)	So why is there less water now?
Answer1: (05:25)	Because you put the tissue inside the water (*Boy)*
Question: (05:31)	And what did the tissue do*?*
Answer1: (05:36)	The tissue is begin to become to be red (*Girl)*
Answer2: (05:45)	The tissue went out of the water and come out with some water (*Girl)*
Question:(05:55)	The tissue took some of the water?
Answer1: (05:57)	Yes !!! (*Majority of the learners shout out)*

He refills the water in the cylinder and uses more tissue paper for the experiment

Question: (06:46)	Is it a big piece or a small piece?
Answer1: (06:49)	Big!!! (*Majority of the learners shout out)*
Question: (06:52)	What is going to happen if I put this big piece in the water?
Answer1: (06:56)	The water will be short *(Girl)*

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Answer2: (07:01)	The toilet paper will be small *(Girl)*
Answer3: (07:06)	The toilet paper will be red (*Boy)*

After he has put the tissue paper in and then out of the water

Question: (08:08)	What happened?
Answer1: (08:12)	The water is down *(Boy)*
Answer2: (08:22)	The toilet paper take the water away *(Boy*)
Question: (08:34)	Why did it take so much water?
Answer1: (08:36)	Because there is too much tissue *(Boy)*
Answer2: (08:51)	Because the tissue is small (*Boy)*

Video 4

Demonstration of propulsion using: The balloon, straw and gut

Mr Naude shows the learners how the straw moves

Question: (00:12)	What is this?
Answer1: (00:14)	A balloon (*All the learners shout out)*

He blows the balloon and attaches it to the straw

Question: (00:37)	What is going to happen if I let go of the balloon?
Answer1: (00:43)	The straw is going to move with the balloon (*Boy)*
Question: (00:48)	In which direction will it move?
Answer1: (00:51)	That way *(The majority of the learners point to the specific direction.*
Question: (01:01)	Why do you say so?
Answer1: (01:04)	Because the balloon is facing that way (*Boy)*
Answer2: (01:07)	Is going to go to the left hand side (*Girl)*
Question: (01:21)	Which side show me with you finger which side?
Answer1: (01:22)	***All the learners point to their right hand side***
Question: (01:25)	Who of you say the balloon will go that side? Pointing to his left?
Answer1: (01:27)	***Some learners raise their hands***
Question: (01:28)	Who of you say the balloon will go that side? Pointing to his right?
Answer1: (01:29)	***Some learners raise their hands***

After he lets go off the balloon while on the gut

Question: (01:45)	Who was right?
Answer1: (01:47)	***Some learners raise their hands***
Question: (01:49)	Why did the balloon go this way?
Answer1: (01:58)	Because the mouth of the balloon is facing that way *(Boy)*
Question: (02:03)	Because the mouth of the balloon is facing this way the balloon went that way, but why?

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Answer1: (02:12)	Because the line of the balloon was that way (*Boy)*
Answer2: (02:33)	Because the balloon was in the middle *(Girl*
Answer3: (02:45)	Because the string starts her and……..(*Girl)*
Question: (03:03)	If I turn the balloon that way where is it going to go?
Answer1: (03:22)	It will go that way pointing to the right (*Boy)*
Question: (03:43)	If we let nonkululeko stand on a chair and the string is up which way will the balloon go?
Answer1: (04:12)	That way(*Learners point to the specific direction)*
Question: (04:28)	Did you see it went up?
Answer1: (04:29)	Yes!!! (*All the learners shout out)*
Question: (04:31)	Why did it go up?
Answer1: (04:34)	Because the string was up *(Girl)*
Answer2: (04:40)	Because the string is facing up *(Boy)*
Answer3: (04:47)	Because the mouth was facing there *(Boy pointing at the direction)*
Question: (05:03)	Can you see the string is facing down which direction will the balloon move?
Answer1: (05:12)	***Learners use their fingers to show the direction***
Question: (05:31)	Why did it go that way?
Answer1: (05:36)	Because the string was down (*Girl)*
Answer2: (05:42)	Because the string was facing down *(Girl)*
Answer3: (05:56)	Like a pencil when you put it there, the is goner go down *(Boy)*
Answer4: (06:12)	Because the string is facing down then the balloon go down *(Girl)*
Question: (06:34)	You said if I put the string up the balloon will go up and if I put it down it?
Answer1: (06:36)	Down!!! *(The majority of the class shouts out)*

The end

APPENDIX C: INDIVIDUAL TASK-BASED CLINICAL INTERVIEW PARTICIPANT DETAILS

Date	Participant Code	Time start	Time End	Total Time
06/03/2017	FF38	10:30	11:10	40 minutes
06/03/2017	FM38	12:05	12:45	40 minutes
06/03/2017	FF31	12:55	13:35	40 minutes
09/03/2017	FF32	08:20	08:40	20 minutes
09/03/2017	FF33	08:55	09:30	35 minutes
09/03/2017	FF34	10:25	11:00	35 minutes
09/03/2017	FF35	11:40	12:15	35 minutes
09/03/2017	FM31	12:40	13:05	25 minutes
09/03/2017	FM32	13:15	13:55	40 minutes
13/03/2017	FM33	09:05	09:30	25 minutes
13/03/2017	FM36	10:20	10:50	30 minutes
13/03/2017	FM37	11:00	11:25	25 minutes
20/04/2017	FFR4	08:20	08:45	25 minutes
20/04/2017	FFR1	08:55	09:25	30 minutes
20/04/2017	FFR2	10:20	11:50	30 minutes
04/05/2017	FFR3	08:45	09:20	35 minutes
04/05/2017	FFR5	09:30	10:10	40 minutes
04/05/2017	FMR2	11:15	11:40	35 minutes
04/05/2017	FMR3	12:00	12:35	35 minutes
10/05/2017	FMR5	08:20	08:55	35 minutes
10/05/2017	FMR6	09:05	09:35	30 minutes

APPENDIX D: VIDEO RECORDINGS AND TRANSLATIONS OF INDIVIDUAL TASK-BASED CLINICAL INTERVIEWS

Videos have been placed on a cloud-based server to serve as example of the individual task-based interviews. The following hyperlinks can be used to access these videos:

Participant Code	Video Recording	Translated Recording
FMR5	https://drive.google.com/open?id=1GETPXLnUlsZkhfpmV9MhCYaBAN483tYY	https://drive.google.com/open?id=1PUFf2aGHpryFnh-ejd8Z9wfaBE-0k4uh

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APPENDIX E: DATA ANALYSIS: EXAMPLES OF CODING PROCESS

The following document was placed on a cloud-based server as example of the initial data analysis process showing the raw codes as derived from the interviews:

Meta data for Clinical interviews[7]:
https://drive.google.com/open?id=1DX6USLj4-C85imEhJr8uaTtUY6EOAhrJ

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[7] Copy and paste the URL into an internet browser search bar in the event that the link does not work.