**Teacher Knowledges, Classroom Realities:
Implementing Sociocultural Science in New Zealand
Year 7 and 8 Classrooms**

Dayle Anderson

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Abstract

Lack of science content knowledge has often been suggested as underpinning primary teachers' reluctance to teach science or to provide limited learning opportunities when doing so. Understanding better the full range and nature of teacher knowledges that afford useful science learning opportunities in primary science education could produce a more positive view of primary teachers' potential for science teaching and usefully inform professional development in science. This research used a multiple case study approach to identify the nature of knowledges and beliefs that three teachers from schools well regarded for teaching science at Years 7 and 8 brought to their implementation of a unit of work in science. Students' perceptions of learning pertaining to the science unit were also examined. The influence of teacher knowledges on opportunities for science learning was considered and the ways in which the teachers developed science related teacher knowledges was investigated.

Sociocultural theories of learning underpin this study and the extent to which the teachers incorporated sociocultural approaches in their science teaching was a particular focus. Frameworks guiding the analysis of the range of teacher knowledges and of sociocultural teaching approaches were developed from the literature. Data for each case study included observations and transcripts of recordings of the lessons forming each science unit together with multiple interviews with the teacher throughout its implementation. Interviews with focus students during and following the unit along with responses to a questionnaire completed by the class at the end of the unit provided insights into students' perceptions of what they had learned.

This study found that the teachers drew on a wide range of knowledges and beliefs to promote science learning. The teachers employing sociocultural approaches afforded most syntactic science learning opportunities. Crucially influential on the nature of science learning that was promoted was the teacher's orientation to science teaching, in particular, beliefs about the purposes and nature of science and science teaching. Four processes were identified that facilitated the teachers' development of science and pedagogical content knowledge: intentional development, reflection,

repetition, and engaging and observing students in investigating the natural world. The nature of knowledge developed by each teacher was afforded and constrained by their orientation to science teaching and their recognition of and access to, sources of support. Learning science content, i.e., substantive science learning, was identified by students where this had been the focus of learning and assessment opportunities because of their teacher's particular orientation. Learning about the nature of science, i.e., syntactic science learning, was identified where this was the sole focus of learning and assessment opportunities. In the one case where the teacher's orientation afforded *both* types of learning opportunity with apparently equal emphasis, students more readily identified substantive science ideas over syntactic ideas as new or important learning.

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CHAPTER 1

Introduction and Overview

1.1 Introduction and rationale

The extent and nature of the science content knowledge exhibited by primary teachers has often been highlighted as problematic in New Zealand and internationally (Appleton, 2006; Education Review Office, 2002, 2004, 2010; Harlen, 1999; Lewthwaite, 2000; Osborne & Simon, 1996; Russell, Qualter & McGuin, 1995). Lack of content knowledge was identified as a major concern expressed by primary teachers in implementing the New Zealand science curriculum (McGee et al., 2003). The New Zealand Education Review Office [ERO] noted in 2004 that only 48% of primary schools reviewed were effective in implementing the science curriculum: “A lack of confidence in teaching science, generally as a result of a lack of science content knowledge, was regularly noted to be the key factor in less effective performance” (ERO, 2004, p.13).

However, despite this, there is evidence that some primary teachers do successfully engage their students and foster learning in science (Appleton, 2006; ERO, 2004, 2010; Tiplady, 2004). Hattie (2009) discusses the “conundrum” of teacher subject matter knowledge (p.127). His synthesis provides little evidence linking teacher content knowledge with student achievement and asks how teachers with low content knowledge have such positive effects. The significance of factors such as quality of teaching and teacher-student relationships suggests that other types of knowledge have a role.

As a science teacher educator, past primary teacher and scientist, I find a deficit view of primary teachers with regard to science content knowledge unhelpful. Primary teachers I have worked with have many attributes useful for teaching science. What knowledge do well regarded primary teachers of science draw on in their practice? Does their general teaching knowledge help their science teaching? How do they develop the scientific knowledge they need? Investigating these questions could provide information that may support less confident teachers and was a major impetus in beginning this research.

1.2 The context for the study

The following sections describe the context for this study, both personal and national.

1.2.1 Personal stance and perspective

I was born and educated in New Zealand. My interest in science developed from the age of fifteen when an appreciation of the power of science to provide explanations about how the world worked developed from my chemistry studies. My understanding of chemical structures and their influence on reactions continued and extended during my university studies, culminating in a research project at postgraduate honours level in biochemistry investigating the physical and chemical structure of haemocyanins, the oxygen carrying proteins in crustacea. After working as a scientist for eight years investigating the nature of resistance of bacteria to antimicrobials, I became interested in primary teaching. I undertook my initial teacher education, and worked for seven years as a primary teacher and deputy principal. My interest and expertise in science was reflected in my being made teacher in charge of science at my school and resulted in a secondment to facilitate professional development in science using newly developed *Making Better Sense of the Material and Physical World* books. I later was appointed as a lecturer in primary science and mathematics education at the Wellington College of Education, now the Faculty of Education at Victoria University of Wellington.

During my time as a science teacher educator I have reflected on and developed my thinking in two interrelated areas central to this thesis – how people learn and the nature of science. I began my career in science education as a constructivist; my own understanding was very clear to me and the view that more fruitful ideas and connections replaced and extended less useful ones seemed logical and relevant to my own learning. My early focus in science education focused on helping beginning teachers to identify key science concepts relevant to a topic, and finding ways to determine their students' science conceptual understanding and guide them toward a more scientifically accurate understanding. I gave little thought to the messages this sent to both teachers and students about what science is. Critique in the literature concerning the adequacy of such conceptual change approaches in preparing students to be scientifically literate citizens and subsequent changes in curriculum requiring teachers to address the nature of science as a major focus for their teaching have made me reconsider my early science experience, how I learnt about the nature of scientific knowledge, and the processes and values that surround its generation and acceptance. Such reconsideration has led to my seeing

science, not only as a set of valuable explanations that can be applied in our daily lives, but also as a set of cultural practices in which I gradually learned to participate. With hindsight, I can see that the ways of science were not made explicit to be learned, but were adopted as I became part of the community of scientists. They were accepted by me uncritically and unwittingly. By stepping out of my original career as a scientist and viewing science from the outside as a science educator I have had the opportunity to consider the nature and generation of scientific knowledge. Processes and values that were once implicit in my experience and practice were identified and considered: the need for sound evidence; the role of the scientific community in critiquing methodology, analysis and interpretation of data; and understanding how and why accepted theories change over time as new evidence is brought to light, often through new technologies, and old evidence is reconsidered. The significance of such understanding has been highlighted through reports describing public perceptions of science and discussions with my teaching students that have made me see that science is viewed negatively by many non-scientists who often also uncritically accept untested ideas and explanations. I therefore see *both* the knowledge produced by science and knowledge about the processes and values governing the generation of that knowledge as important for students to understand if we are to develop a critical and responsible citizenry. A focus in this study is therefore the development of both these types of knowledge.

1.2.2 The New Zealand context

Schooling in New Zealand is compulsory from ages six to sixteen. Primary schooling usually begins at age five in Year 1 and continues through to Year 8 in Māori, Pasifika or, most commonly, English medium schools. Most Year 7 and 8 students attend either a primary school for Years 1 to 8 or an intermediate school for Years 7 and 8 (Ministry of Education [MOE], 2009). New Zealand's foundational document, the Treaty of Waitangi, an agreement between Māori (the indigenous people of New Zealand) and the British Crown, promises partnership and equity for the co-signatories. As part of their registration criteria New Zealand teachers are obliged to demonstrate commitment to bi-cultural partnership and to respond to the increasingly diverse language and cultural experiences of individuals and groups (New Zealand Teachers Council, 2009).

Within this schooling system science is now one of eight learning areas for primary students in an increasingly full and complex curriculum, to which learning languages has been recently added along with the need to develop key competencies and values (Barker, 2008a). Two national curriculum documents, *Science in the New*

Zealand Curriculum (MOE, 1993a) and its successor, *The New Zealand Curriculum* (MOE, 2007), guided English medium science teaching at different times during this study. Both documents are “outcomes-focused”: they set out what students should “know and be able to do” (MOE, 2007, p. 4). Both documents contain science contextual strands, each with aims and achievement objectives for different levels of schooling. These strands outline broad conceptual understandings within four sub-disciplines of science: Living World, Material World, Physical World, and Planet Earth and Beyond. The 1993 document specifies four sets of skills focused on development of scientific inquiry. Both documents include outcomes concerning understanding of the nature of science, i.e., the characteristics of the scientific discipline. The 1993 document specifies that these outcomes are to be integrated with the contextual strands. These objectives strongly link science with the development of technology. The 2007 document makes the Nature of Science strand required learning for all students to Year 10, and describes it as the “overarching unifying strand” (p. 28). The contextual strands provide “contexts for learning” (p. 29) and should all be experienced by students over the course of Years 1-10. The Nature of Science strand has four sub-strands. The Investigating in Science sub-strand links process outcomes with developing knowledge and explanations. For example, younger primary students should “extend their experiences and personal explanations of the world through exploration, play, asking questions, and discussing simple models” (MOE, 2007, p. 47). The other three sub-strands are: Understanding about Science, Communicating in Science and Participating and Contributing. Both documents encourage a broad focus to allow teachers to meet the needs of their students. The 2007 document localised design of school curriculum to “best address the particular needs, interests and circumstances of the school’s students and community” (p. 37). The purpose of the 1993 document is described as providing “science for all” (p. 11); both citizenship and career goals are proposed. Similarly, the stated purpose of the 2007 document is that students participate as “critical informed and responsible citizens in a society in which science plays a significant role” (p. 17).

In practice, there is considerable variability in the amount and type of science learning experiences that primary schools offer (ERO, 2004, 2010). At Year 5, as measured in 2006 by the Trends in International Mathematics and Science Study, teachers reported spending significantly less time on science than in 2002, and student achievement, which had been increasing steadily until 2002, had by 2006 returned to 1994 levels. New Zealand European and Asian student achievement was, on average, significantly higher than that of Māori and Pasifika students

(Caygill, 2008). In the National Education Monitoring Project findings for 2007 in science, numbers of middle and senior primary students reporting that their class never did experiments with everyday things or science equipment increased significantly from 1999 levels, and those reporting they learned little about science nearly doubled (Crooks, Smith, & Flockton, 2008). Many primary schools integrate science with other learning areas to teach “Topic” in a multidisciplinary general inquiry approach: students may not be recognising the science they are doing (Bull, Gilbert, Barwick, Hipkins & Baker, 2010).

New Zealand primary teachers are commonly generalist; they are responsible for implementing all eight learning areas in the 2007 curriculum. Few have a science background (Bull et al., 2010). International comparisons show New Zealand primary teachers receive relatively little pre-service science education and less ongoing science professional development (ERO, 2010; International Association for the Evaluation of Educational Achievement (IAEEA), 2007). Numeracy and literacy have been the focus of MOE initiatives developed in response to the concerns expressed in the Report of the Literacy Taskforce (MOE, 1999) and the Report of the Mathematics and Science Taskforce (MOE, 1997) instigated in response to New Zealand’s poor results in international studies (Garden, 1997). Science was not included in these initiatives, despite being a focus of the taskforce report, although two sets of primary science teacher support materials were developed in response and placed free in all New Zealand primary schools: the *Making Better Sense* series, one book for each of the four contextual strands of the curriculum providing key science ideas on given themes with related practical activities to support conceptual development (e.g., MOE, 2001), and the *Building Science Concepts* series of 64 books on thematic topics, again providing concepts and activities (e.g., MOE, 2002). The introduction of the 1993 science curriculum (MOE, 1993a) and the *Making Better Sense* series was supported by MOE funded professional development. This was voluntary, of short duration, and out of school hours. Teacher support for the Nature of Science strand has been provided since 2005 on the MOE website (www.tki.org.nz) with modifications to match the 2007 curriculum appearing from 2010 (C. Arcus, personal communication, August 12, 2011). Since 2007 the Science Learning Hub (<http://www.sciencelearn.org.nz>), funded by the Ministry of Science and Innovation, has provided New Zealand focused science resources and teaching ideas that include the Nature of Science strand. These were originally aimed at secondary school levels, but more recently have targeted upper primary as well.

Consideration of the New Zealand primary science education context raises two issues pertaining to the nature of teacher knowledge it requires. The first is the increasing curricular focus on outcomes concerning the nature of science. Schwab (1964) described two kinds of discipline knowledge: *substantive* knowledge, which refers to understanding of the body of knowledge generated *by* a discipline, and *syntactic* knowledge, which is knowledge of the means by which ideas are developed and become accepted within it. Both types of knowledge outcome are required by the New Zealand curriculum, with the latter being given most importance in the 2007 curriculum. The second issue is the need for a science education meaningful for students from a range of cultures located in a bi-cultural context. These two issues require far more of teachers than understanding science content. A further issue pertains to students' perceptions of science learning: if students are unaware that they are learning science or that they have made gains in understanding about science, what needs to happen in the classroom to ensure they become aware? Internationally, Abell (2007) notes that science research literature that examines the influence of teacher knowledge on student learning is lacking:

Science education researchers should make more efforts to connect what we know about teacher knowledge to student learning. Although we have a good understanding of the kinds of knowledge that teachers bring to bear on science teaching, we know little about how teacher knowledge affects students. (p.1134)

Hipkins et al. (2002) suggested that little local evidence is available concerning the nature of current New Zealand classroom practice and the extent to which the effective pedagogies they identified, many of which could be part of a sociocultural approach, are utilised. There is little documented concerning "the curriculum experienced by students and on students' perceptions and beliefs about science" (p. 241). Duit and Treagust (2003) suggested that many students conceptualise science learning as an accumulation of facts and this influences their views as to what counts as work in school science.

These problems are compounded by lack of time both in the classroom and in teacher education, the hours for which, in my experience as a teacher educator, have decreased further since the 2007 report cited earlier (IAEEA, 2007). All of these issues together suggested the major question for the present study: what knowledge do New Zealand primary teachers need that will enable them to use the limited time available so that all students are afforded opportunities to recognise and develop the substantive and syntactic outcomes expected for science in the national curriculum?

1.3 Toward a sociocultural perspective

The issues described above raised questions about teacher knowledge but also theoretical concerns.

Constructivism has had major influence on science education. Knowledge is seen as developing through successive constructions from interactions with the physical world as perceived through the senses. If ideas are not easily assimilated by existing structures in the mind of the learner, then contradictions create a disequilibrium that is resolved in accommodation through a process of equilibration (Barker, 2008b; Bell, 2005a; Fosnot & Perry, 2005). Mental structures are expanded and transformed, becoming more organised and reorganised (Fosnot & Perry, 2005). Existing science knowledge is reconstructed as “new personal knowledge” by the learner (Bell, 2005a, p. 34).

Constructivism underpinned significant New Zealand research, summarised by Bell (2005a), that developed a teaching model which identified and addressed students’ naive science conceptions (Osborne, Freyberg & Tasker, 1980). Conceptual change strategies associated with curriculum reforms in the 1990s in the United States were also based on constructivist theories (Smith, 1999). Concerns exist that constructivist teaching approaches lack the ability to critique the generation of new knowledge (Duit & Treagust, 2003; Gilbert, 1997, as cited in Bell, 2005a). Reformers (e.g., Driver, Leach, Millar, & Scott, 1996; Duschl, 2008; Osborne, 2007) suggest that conceptual outcomes are not sufficient for today’s society and that a cultural outcome for science education is needed: “how we know what we know and why we believe it” (Duschl, 2008, p. 269). This direction is encapsulated in both the 1993 and 2007 New Zealand curriculum documents. Sociocultural approaches appear best placed to support such outcomes (Duschl, 2008). Hipkins et al. (2002) surveyed the science education literature to propose a list of recommendations for effective science pedagogy in the New Zealand context of the 1993 curriculum. Many of their recommendations support participatory aspects of sociocultural approaches to science teaching.

Many commentators suggest that a purely conceptual learning approach is inadequate. Anderson (2007) argues that despite deliberate attention to students’ prior conceptions in constructivist approaches, some students still do not achieve the desired learning goals. Lemke (2001) states the “apparent assumption of conceptual change perspectives in science education ... is that people can simply change their views on one topic or in one scientific domain, without the need to change anything else about

their lives or their identities” (p. 301). Longitudinal studies (e.g., Peterson & Tytler, 2001) demonstrating that learners’ science conceptions form part of a personal narrative, influenced by their views of themselves as learners, personal events and contexts, similarly suggest that a more situated view of science learning may be necessary.

Sociocultural theories view learning as increasing participation in a community of practice that is socially, culturally and historically located, through socially mediated action (Lave & Wenger, 1991; Wenger, 1998; Wertsch, 1991). Cognition is seen as distributed to various extents and at different times across the surround and members of a community of practice (Bell, 2005a; Lave & Wenger, 1991; Rogoff, 2003). Understandings of students as culturally located beings and science and classrooms as cultural communities of practice have been used by Aikenhead (1996) to support a view of learning science as an act of border crossing between cultures. Barker (2008b) suggests teachers facilitate border crossings. Wenger (1998) himself outlines the role of brokers, namely people who can participate in more than one community of practice and therefore introduce aspects of one community into another. Primary teachers can be seen to be assisting their students to make this border crossing. Aikenhead (1996) suggests the nature of this border crossing can range from cultural imperialism, through forced assimilation to a more gentle approach of enculturation. As Carlsen (2007) states, “learning may be easier when teachers strive for instructional congruence between the academic culture and the culture of their students, modifying subject matter by using students’ language and cultural experiences” (p. 61).

These descriptions suggest that sociocultural theory is a useful lens through which to examine the teaching of science for the purposes of this thesis. It can account for students coming to appreciate and apply both substantive and syntactic forms of science knowledge through enculturation and participation. It suggests that teacher knowledge other than science content may contribute to such enculturation in a New Zealand context. Sociocultural theory also highlights problems of access for most primary teachers to scientific ways of thinking and doing. That New Zealand primary teachers are commonly not members, even peripherally, of the scientific community raises the question as to how such teachers develop the knowledge they need to teach science. Another question is suggested by proposals that sociocultural teaching approaches may best support science education: to what extent do generalist New Zealand primary teachers espouse and practise sociocultural approaches, particularly in science, and how does this influence the science learning opportunities afforded?

This thesis will be investigating how the knowledges held by teachers, such as knowledge about students and general curriculum, may be useful in science lessons. Adopting sociocultural theory is not unproblematic in this regard. Sociocultural theory suggests that successful learning is competent participation in a community of practice: learning is bound intrinsically to its context. That knowledge is something to be acquired and carried from one situation to another does not fit well. Sfard (1998) addresses these two metaphors of learning: participation, as epitomised in sociocultural theories, and acquisition. Regarding teachers as holding and developing particular knowledge falls into the latter category. Sfard concludes that neither metaphor is sufficient on its own, suggesting that ways of accommodating both are possible: they could be regarded as “different perspectives” rather than “competing opinions” (p.11). Science itself lives with duality of theories, Newtonian versus quantum physics for example. Sfard practically points out the usefulness of carrying “something” from one context to another. Traianou (2006) describes in sociocultural terms how such transfer occurs:

Throughout their lives, individuals participate in various communities of practice, ranging from scholarly disciplines such as science or history to groups of people sharing a common interest, including those operating in particular classrooms. Each of these communities generates tools, a set of shared social meanings, which its members use to interpret and negotiate their interpretations with one another, thereby enabling them to continue to act successfully in the activities of that community. In the course of this process, people develop, often tacitly, rich networks of links between specific tools and situations, which are employed to make sense of future situations. And because situations are not fixed or identical, each time an individual uses a tool to construct understanding of a new situation that resembles an old one, he/she develops a better understanding of both the tool and the situation itself. (p. 835)

In this thesis “knowledge” is interpreted socioculturally, providing a shorthand for the “rich networks of links between specific tools and situations, which are employed to make sense of future situations” (Traianou, 2006, p. 835), i.e., the “something” that is transferred between contexts (Sfard, 1998). However, I also acknowledge the active and changing nature of “knowledge” implied. Knowledge, as I perceive it and as used in this study, is acquirable but is constantly reshaped through its application in different contexts.

1.4 Research questions for this study

This chapter examined the New Zealand context for primary science teaching and developed an overarching question: what knowledge do New Zealand primary teachers need that will enable them to use the limited time available so that all

students are afforded opportunities to recognise and develop the substantive and syntactic outcomes expected for science in the national curriculum?

As discussed at the beginning of this chapter, some New Zealand teachers overcome the inherent problems to teach science in ways that engage students and that are well regarded by experts (ERO, 2004, 2010; Tiplady, 2004). Talking with and observing the practice of highly regarded primary science teachers and their students through a multiple case study approach (Stake, 2006), would allow detailed examination of teacher knowledges and their influence on science teaching practice and student perceptions in situated contexts, in keeping with the sociocultural perspective applied in this study. Such an approach would elucidate answers to the four research questions developed for this study that will inform the major question stated above:

1. What knowledges do highly regarded generalist primary teachers of science bring to their teaching of science, and how do these knowledges influence learning opportunities in science?
2. How do these teachers develop the knowledge they need for teaching science?
3. To what extent do these teachers espouse and practise sociocultural approaches, particularly in science, and how does this influence learning opportunities in science?
4. What perceptions do students participating in science units implemented by these teachers, each exhibiting a particular set of knowledge and beliefs, have of their science learning?

1.5 Thesis overview

This chapter has described the context for this study and developed the research questions that guide it. Chapter 2 reviews the literature on the nature of teacher knowledge and development of knowledge for science teaching. Two frameworks are developed, one to guide analysis of data with regard to teacher knowledge and one to support analysis of data with regard to sociocultural teaching approaches for science. Chapter 3 describes the methodology and means of data collection and analysis used for this study. Chapters 4, 5 and 6 record the analysis of data from each of the three cases forming this study. Chapter 7 compares and analyses findings from all three cases in conjunction. Chapter 8 presents the findings of the study, discusses implications, and raises questions for further research.

CHAPTER 2

Literature Review

2.1 Introduction

The first two sections of this chapter review the literature concerning models and frameworks of teacher knowledge to develop one suitable to support analysis of data in this study. The first identifies frameworks common in the literature and the second reviews research contributing to decisions concerning content of each domain in the framework used for this study. The third section reviews research concerning the development of the knowledge needed for science teaching. Literature about sociocultural theory is then used to develop a framework for analysis of data with regard to sociocultural teaching approaches.

2.2 Theories and frameworks of teacher knowledge

Fenstermacher (1994) described four major streams of research centred on teacher knowledge: teachers' practical knowledge (e.g., Clandinen & Connelly, 1996); the teacher as researcher movement (e.g., Cochran-Smith & Lytle, 1999); the teacher as reflective practitioner (e.g., Schön, 1983); and, lastly, the work of Shulman (1986, 1987). Shulman's categorisations focused on the whole knowledge base required for teaching, including teaching a particular discipline (Abell, 2007). Since the purpose of this study is to identify the nature of knowledge used in, and useful for, teaching primary science in a New Zealand context, Shulman's categorisations provide a useful starting point.

2.2.1 Shulman's articulation of the knowledge required for teaching

In the 1980s Shulman identified that a lack of a specialised and coherent knowledge base for teaching existed in the United States amid calls for improved teacher evaluation and professionalism (e.g., Carnegie Task Force on Teaching as a Profession, 1986). He suggested seven areas of knowledge useful for teaching (Shulman, 1986, 1987). His ideas arose from a research programme examining knowledge exhibited by new and experienced secondary school teachers, but their power has been in the research they have generated, providing a way to examine "what it is that a teacher knows and is able to do." (Berry, Loughran & van Driel, 2008, p. 1275). The seven categories he described are listed below:

- General pedagogical knowledge, with special reference to those broad principles and strategies of classroom management and organization that appear to transcend subject matter

- Knowledge of learners and their characteristics
- Knowledge of educational contexts, ranging from workings of the group or classroom, the governance and financing of school districts, to the character of communities and cultures
- Knowledge of educational ends, purposes, and values, and their philosophical and historical grounds
- Content knowledge
- Curriculum knowledge, with particular grasp of the materials and programs that serve as “tools of the trade” for teachers
- Pedagogical content knowledge, that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding. (Shulman, 1987, p. 8, in order as described in Ball, Thames & Phelps, 2008, p. 391)

Shulman identified scholarship in content disciplines as an important source of the knowledge required for teaching, including in this both of Schwab’s (1964) categories of substantive and syntactic knowledge. He also identified a category of specialist knowledge for teaching which he entitled pedagogical content knowledge (PCK). He highlighted this category as being that most likely to differentiate the “pedagogue” from the “content specialist”. It “represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organised, represented and adapted to the diverse interests and abilities of learners, and presented in instruction” (Shulman, 1987, p. 8).

Shulman’s categories have proved a useful heuristic in assisting researchers to identify distinctions in teacher knowledge that make a difference for effective teaching (Ball et al., 2008). The first four categories described dimensions that already comprised the mainstay of teacher education programmes; thus they were not the main focus for Shulman’s articles. He emphasised these were still crucial; combining them with content dimensions was vital for effective teaching (Ball et al., 2008). These areas may offer utility for science in the knowledge base of generalist primary teachers.

2.2.2 Models of teacher knowledge derived from Shulman’s articulation

Researchers have modified Shulman’s domains of teacher knowledge in various ways, some theoretical and some empirical. For example, based on evidence from case studies of beginning teachers of English, Grossman (1990) combined Shulman’s knowledge of learners with general pedagogical knowledge and added knowledge of curriculum and educational purposes to PCK to form four general areas of teacher knowledge she described as “cornerstones” of teacher knowledge: subject matter knowledge, general pedagogical knowledge, knowledge of context and PCK. Cochran, DeRuiter and King (1993), in their theoretical model, developed

the knowledge of students domain to form a “cornerstone” category of its own and expanded knowledge of contexts to include understandings of social, political, cultural and physical environments. In using pedagogical content *knowing* (PCKg), they argued their framework more accurately reflected the continuous integration of learning characteristic of constructivist views. More recent theoretical knowledge frameworks considering components for teacher education programmes include an understanding of diversity and the role of culture in teaching and learning, reflecting a more sociocultural approach to education (Darling-Hammond & Bransford, 2005; Grant & Gillette, 2006; Imig & Imig, 2006).

Magnusson, Krajcik and Borko (1999) developed a conceptualisation of the nature of knowledge needed for science teaching. Their overall framework reflected Grossman’s four cornerstones, but they further developed PCK specifically for science. Theirs was a theoretical rather than empirical model, although it drew on a range of research. It has formed the basis of much recent research into teacher knowledge in the field of science education (Friedrichsen, Van Driel, & Abell, 2011). Abell (2007) used their model of PCK together with features of Grossman’s to frame her summary of research in the area of teacher knowledge for science. Kind (2009a), after comprehensive review, identified that their model of PCK encompassed best the needs of science teacher education. Hashweh (2005) used Shulman’s categories in a model describing formation of teacher pedagogical constructions for science, his version of PCK.

Teacher knowledge frameworks derived specifically from or for primary contexts are few. Shulman (1987) noted that, while reasonably confident, he was not sure that his emphasis on the centrality of content knowledge held true for elementary teachers. A longitudinal study of pre-service primary teachers resulted in Turner Bisset (1999) adding to Shulman’s domains the knowledge of self, as she found teachers’ prior experiences impacted on their teaching. She also included Grossman’s beliefs about the purposes of a subject and included all knowledge domains within PCK. Tiplady (2004) studied science content knowledge development in New Zealand primary teachers and developed Cochran et al.’s (1993) model to include all four of their domains as part of PCK, together with attitude, interest and enthusiasm. As with Turner-Bisset, teachers’ background knowledge was found to contribute to knowledge for teaching.

Abell (2007) suggested that research into teacher knowledge has suffered as researchers have tended to invent and add their own dimensions to the construct

which are used once or twice and then fade, making the contribution of the research to the wider knowledge base difficult to ascertain. The implication for this study is to use domains of teacher knowledge commonly and clearly characterised in the research literature to frame the inquiry. Shulman's categories therefore form the basis of the knowledge framework used for analysis in this study. The language and definitions used have become a common tool for discussing and representing teacher knowledge. His domains are clearly present in frameworks commonly used in science education literature and so provide commonality with established research (Abell, 2007; Kind, 2009a).

2.3 Development of the framework of teacher knowledge used in this study

Many of the models discussed above grouped and connected Shulman's categories. The purpose of the framework developed here is to identify the teacher knowledge apparent in data, at least initially. Interconnections between domains are therefore not part of this discussion, but will be discussed with relation to PCK development in Section 2.4. In this section the research literature is examined (using Shulman's categories as domain headings) to provide detail concerning the components of each domain in the framework for this study. Berry et al. (2008) suggest that, because of varying definitions, researchers have looked for, and valued, different aspects in attempting to identify a knowledge base for teaching. Thus commonly defined components within each domain are incorporated; however, aspects not commonly included in other frameworks are also evaluated for their relevance to sociocultural approaches, primary science teaching or the New Zealand context, and are clearly defined. For example, models of teacher knowledge for science have not traditionally addressed teachers' syntactic knowledge or its pedagogy, despite Shulman (1986, 1987) including syntactic knowledge within the content domain; Abell (2007) excluded syntactic knowledge research from her review, possibly as another chapter in the volume covered this subject. Given the expectations of the current New Zealand curriculum concerning the nature of science, these aspects are discussed here and are deliberately incorporated under Shulman's domain headings in order to compare findings with evidence from other research.

2.3.1 Inclusion of beliefs

The distinction between knowledge and beliefs is not always made clear in research or agreed upon by researchers (Abell, 2007). Calderhead (1996) defined knowledge as "the factual propositions and the understandings that inform skilful action" and

beliefs as “generally referring to suppositions, commitments, and ideologies” (p. 715), suggesting beliefs often incorporate an ideal view that contrasts with reality and therefore can summarise goals and paths. He described how beliefs are linked with affective and evaluative components. For instance, teachers’ beliefs about the nature of subjects are strongly associated with ideas about what children should learn within those subjects. This is pertinent with regard to science. Appleton (2006) stated that primary teachers often view science as a complicated set of facts and definitions to be found in accurate sources such as books and scientists, beliefs that impact on the nature of teaching and learning that occurs. Magnusson et al. (1999) suggested that orientation toward the teaching of science is an important component of teacher knowledge influencing the nature of learning opportunities. Friedrichsen et al. (2011) suggested this construct depends on a complex set of teacher beliefs that need further exploration as to their nature and connection with practice. Magnusson et al. (1999) provided evidence from several research projects wherein teachers refused to change their instructional strategies because the new strategies did not fit with their beliefs about the teacher’s role. Abell (2007) cited research by Duffee and Aikenhead (1992) showing that teachers’ science assessment choices were mediated by their beliefs. Calderhead (1996), in reviewing the research on this issue, found that evidence was not clear as to the degree to which beliefs affect teacher practice; a number of studies highlighted large discrepancies between teachers’ espoused beliefs and what they did in their classrooms, yet a large number reported consistencies between teachers’ beliefs about the subject or about teaching and learning and their actual practice. Additionally, Hipkins et al. (2002) concluded from their review of literature regarding effective pedagogy relevant to the New Zealand situation that “it would be helpful to know New Zealand teachers’ beliefs and perceptions about the nature and characteristics of science and the purposes of science education” (p. 241).

Given the indications from the literature described above and the potential in this study for data to include a complex mix of knowledge and beliefs, it seemed prudent to include both knowledge and beliefs in the framework supporting analysis for this thesis. There are precedents in the research literature for including beliefs in a knowledge framework; Magnusson et al. (1999) and Turner-Bisset (1999) both included beliefs in knowledge domain headings. Tiplady (2004) incorporated teacher beliefs about learning and teaching science as an encompassing influential factor. Abell (2007) included research on beliefs in her extensive review when it formed part of a “comprehensive knowledge and beliefs system” (p. 1109).

2.3.2 General pedagogical knowledge and beliefs

Though commonly included as part of many teacher knowledge frameworks (Abell, 2007; Appleton, 2006; Bransford & Darling-Hammond, 2005; Cochran et al., 1993; Grossman, 1990; Hashweh, 2005; Magnusson et al., 1999; Tiplady, 2004; Turner-Bisset, 1999), very few authors have focused specifically on the nature of this knowledge domain. Shulman (1987) described it as comprising “the broad principles and strategies of classroom management and organisation that appear to transcend subject matter” (p. 8). Morine-Dershimer and Kent (1999), in their review of research in this domain, found that there were three main areas for consideration within it: general instructional strategies and teaching models; classroom management and organisation; and classroom communication and discourse. These three areas provide useful categories for the teacher knowledge framework for this study. Knowledge of assessment has also been included by some researchers as part of this domain (e.g., Bransford & Darling-Hammond, 2005) but Morine-Dershimer and Kent (1999) argue that it is more closely associated with knowledge of educational ends and purposes, where it has been placed in this framework.

Appleton (2006) suggests strong general pedagogical knowledge may support PCK development. Abell’s (2007) review of this area supports the direction of this study. She concluded that findings of the few studies of science teachers with regard to this domain could relate to teachers of any subject and suggested the interaction of general pedagogical knowledge with science PCK needs research, specifically including investigation as to how classroom management and general views on learning affect science teaching. Views on learning are included in the knowledge of learners and learning domain, but they are also reflected in the definition of instructional strategies examined next.

2.3.2.1 General instructional strategies and teaching approaches

In this section, instructional strategies are discussed and classified according to the learning theories with which they are associated.

Behaviourist theories of learning, based on the work of psychologists such as Skinner, led to presumptions that learners were “passive, in need of external motivation and affected by reinforcement” (Fosnot & Perry, 2005, p. 9). In this approach the hierarchical structure of the discipline was used to structure learning (Bell, 2005a). It was assumed that simply listening to clearly articulated teacher explanations and doing experiments that would elucidate scientific theories would

result in learning if enough motivation was provided and feedback given (Fosnot & Perry, 2005). Practical science work associated with behaviourism is predominantly of the discovery type (Barker, 2008b). Appleton (2006, 2007) and Hodson (2008) both suggest primary teachers favour a discovery approach to science because of their focus on student-centred learning and also perhaps because of their limited views of the nature of science.

Process approaches, common in the 1980s and 90s, reflected aspects of developmental theory with a stepwise staged approach to learning manifested in the learning of the science process skills (Hodson, 2008; Magnusson et al., 1999). In a developmental process approach, scientific inquiry consists of a series of discrete activities including observation, measurement, prediction, hypothesising, classification, data collection and control of variables. Further assumptions include that these processes are generic, independent of context and therefore transferable, and that engaging in these processes will develop scientific knowledge (Bell, 2005a; Hodson, 2008).

Constructivism arose from the field of cognitive science. In later work Piaget returned to redevelop a theory he had proposed earlier to explain the way children learn which involved the processes of assimilation, accommodation and equilibration. In this theory knowledge proceeds from successive constructions. If ideas are not easily assimilated by existing structures in the mind of the learner, then contradictory ideas create a disequilibrium that is resolved in accommodation through a process of equilibration. This may involve ignoring the contradiction and keeping the original idea, maintaining both ideas and making each theory hold for special cases or by constructing a new idea that explains the contradiction (Barker, 2008; Bell, 2005a; Fosnot & Perry, 2005). Mental structures are expanded and transformed, becoming more organised and reorganised, under a constant process of construction (Fosnot & Perry, 2005). The constructivist view of learning is therefore that students construct their own knowledge from their interactions with the physical world as perceived through the senses. Existing science knowledge is then reconstructed as “new personal knowledge” by the learner (Bell, 2005a, p. 34).

Constructivist approaches to learning focus on a personal linking of ideas and experiences and involve identification and restructuring of existing student ideas (Barker, 2008b). Previously described in Section 1.3, constructivist theories are linked with activities such as teaching for cognitive conflict (Palmer, 1996; Swan, 2001) or conceptual change (Posner, Strike, Hewson, & Gertzog, 1982). Socially

mediated forms such as guided discovery and social constructivist approaches to learning where teachers mediate student meaning making through social interaction exist (Barker, 2008b; Magnusson et al., 1999).

Anderson (2007) suggests that research based on conceptual change approaches has focused science educators on listening to students' explanations and encouraging rational and coherent theory building, and have thus encouraged new ways of communicating with students that have led to improved practices in science education, a view that addresses more socially mediated views of constructivism. Many textbooks and curriculum support materials now contain information on common alternative conceptions. This is the case with the *Building Science Concepts* series of 64 books provided by the Ministry of Education to support primary teachers with science (e.g., Ministry of Education, 2002). The books make suggestions as to the key related science concepts that may be significant in developing more sophisticated science understanding. They contain activities that target specific concepts and assist with both diagnostic and formative assessment for conceptual development.

Anderson (2007) highlights two deficiencies in these approaches. The first is apparent in the description of the resources just provided – the emphasis in the approach is largely on conceptual development. The focus is on developing agency with the material world rather than agency with the nature of science. There is a greater focus on the knowledge produced by science than the way in which it is produced. The second deficiency outlined by Anderson (2007) is that despite deliberate attention to students' prior conceptions and inclusion of prerequisite knowledge as part of the programme of instruction, some students still do not achieve the desired learning goals. Anderson asks if there are other features of learning that are not addressed in this paradigm and wonders what science literacy involves beyond conceptual understanding: "a view of students as proto-scientists who understand the world on the basis of implicit theories is not the whole story" (p. 13).

As discussed in Chapter 1, considerations such as those of Anderson described in the previous paragraph led to a focus in this thesis on sociocultural theories of learning. The final group of approaches are those associated with these theories. They also emphasise the importance of socially mediated actions in facilitating learning but focus on participation in authentic activities of a particular community of practice (Grabinger, Aplin, & Ponnappa-Brenner, 2007). While social constructivism

and sociocultural theories of learning have in common beliefs about the importance of socially mediated action, sociocultural theories are differentiated by their view of learning as increasing participation in communities of practice (Lave & Wenger, 1991; Rogoff, 2003; Wenger, 1998) and through the locus for knowledge being seen not as residing within a single individual, but instead distributed over the surround (Bell, 2005a; Eames, 2003; Salomon & Perkins, 1998). Sociocultural theory and practices are characterised in the development of a separate framework identified from the literature in Section 2.5.

2.3.2.2 Classroom management and organisation

Classroom management and organisation was highlighted by Shulman (1987) as forming the major part of general pedagogical knowledge. In their summary of research in this area Morine-Dershimer and Kent (1999) highlighted the work of Brophy and Good whose synthesis of research is summarised as follows: the amount of time students spend on appropriate academic tasks influences academic learning and teachers who structure new information, link it to prior knowledge, monitor performance and provide adequate feedback enable their students to learn more efficiently (Brophy, 1997; Brophy & Good, 1986). Other key teacher behaviours that have been linked with desirable student performance and achievement are: attending to more than one classroom task at a time; identifying and resolving problems effectively and quickly; setting clear expectations for behaviour, work standards and classroom procedures; and systems of consequences (Morine-Dershimer & Kent, 1999). How these aspects affect learning opportunities for science is of interest to this study. Findings from a ten-year longitudinal case study of a new primary teacher suggested strong classroom management needed to be in place before science teaching was implemented well, despite continued positive attitudes toward science teaching (Mulholland & Wallace, 2005). The aspects highlighted by Morine-Dershimer and Kent (1999) form subheadings within this part of the framework guiding this study.

2.3.2.3 Classroom communication and discourse

Morine-Dershimer and Kent (1999) described how student participation and achievement can be influenced by the extent to which students understand and use the rules surrounding classroom interactions. Hipkins et al. (2002) highlighted the importance of discussion for student development of science concepts. Treagust (2007) found teacher questioning and intervention played a significant role in the quality of discourse and ways in which students learned and understood science. Mortimer and Scott (2003) identified four communicative approaches used by teachers with students in secondary science classrooms:

- an interactive/authoritative communicative approach where the teacher builds a high degree of interaction but despite this, little attention is paid in reality to student ideas; they are ignored or discounted. The aim is to reach one specific point of view.
- an interactive/dialogic communicative approach where the teacher likewise creates many opportunities for interaction, but this time multiple ideas are elicited and taken account of even though they may differ from those the teacher is keen for students to adopt. The teacher and student explore ideas, generate new meanings, pose genuine questions and offer, listen to, and work on, different points of view.
- a non-interactive/dialogic communicative approach where attention is paid to more than one point of view but there is little or no opportunity for interaction. The teacher sets out a number of points of view and explores different perspectives but there is no discussion or interaction.
- a non-interactive/authoritative communicative approach where the teacher presents a single point of view with no discussion or interaction.

An ability to manage these discourse forms was helpful in identifying and supporting development of students' scientific concepts.

These four approaches allow ready analysis of class interaction and the opportunities for science teaching and learning afforded and therefore form part of the framework of analysis with regard to classroom discourse.

2.3.3 Knowledge and beliefs about general aims, purposes, and values of education and assessment

Knowledge of educational ends, purposes and values, philosophical and historical grounds was a category of teacher knowledge suggested by Shulman (1987). It was also included in the frameworks of Abell (2007) and Magnusson et al. (1999), who subsumed it into general pedagogical knowledge. Hashweh (2005) referred to beliefs about educational aims of general education. Knowledge and beliefs about assessment have been added to this category as recommended by Morine-Dershimer and Kent (1999).

Fang (1996) discusses discrepancies between teacher beliefs and their practice concerning the purposes of education, suggesting that teachers often need to make choices as to whether to promote equality or excellence, to cover the expected curriculum content or plan learning around children's interests, to help build creativity and independence, or to expect everyone to meet a similar standard. Friedrichsen and Dana (2005), in exploring teachers' orientations to science

teaching (Magnusson et al., 1999), found the secondary biology teachers they studied held multiple goals for their students that varied for different classes and levels. Central goals dominated teachers' thinking, appeared to drive decision making and were highly visible in practice; peripheral goals had less influence than central goals. Goals were general in nature and included preparation for life. Goals concerning the next step in students' education were a common feature for classes where transition to further education was imminent.

In New Zealand primary schools, widely distributed professional development has focused on the use of assessment for improvement of teaching and learning (Poskitt & Taylor, 2008). Cowie (2005) found that assessment relationships with each other, the task and the teacher shaped students' identity as learners and knowers of science and what it meant to know and do science. When assessment used the tools of science and provided students with a sense of agency as well as opportunities to understand how scientists work, it contributed strongly to students' science identities (Cowie, Jones & Otrell-Cass, 2011). Brown (2004) found that New Zealand primary teachers agreed with conceptions that assessment improves teaching and learning and that assessment makes schools accountable, and rejected ideas that suggested that assessment is irrelevant. He suggested this relationship may be because New Zealand schools are self-managing; teachers are accountable for their effectiveness in changing student learning outcomes to their colleagues and to a school-based Board of Trustees made up of parents of students. Teachers' beliefs and knowledge regarding the purposes of assessment in the current study may reflect these views.

This domain is general in nature and in the framework for this study has no other categories than general aims and purposes of education and general aims and purposes of assessment. The interest for this study is in the influence of this domain on provision and nature of science learning opportunities.

2.3.4 Knowledge and beliefs about learning and learners

Knowledge of learners was one of Shulman's (1987) original categories. Hashweh (2005) included knowledge of learning and learners as a separate category in his model of teacher knowledge. Grossman (1990) included knowledge of learning and learners as part of general pedagogical knowledge, as did Abell (2007) and Magnusson et al. (1999). For ease of analysis in the framework for this study this domain has been subdivided into two categories: knowledge of and beliefs about learning and how it occurs, and knowledge of and beliefs about student characteristics, generalised for a particular age group.

With regard to the first category, Turner-Bisset (1999) identified knowledge of child development as a component of primary teacher knowledge that informed practice. Bransford and Darling Hammond (2005) included knowledge of human development and how learning occurs in their suggested knowledge framework for initial teacher education. For the purposes of this study this category includes teachers' cognisance of formal theories of learning as well as their theories in action (Barker, 2008b), ideas and beliefs they articulate about the nature of learning or to justify teaching decisions.

Turner-Bisset (1999) referred to knowledge of, and beliefs about, student characteristics as empirical or social knowledge of learners of a particular age group, in which she included the nature of their classrooms, their school behaviour, interests and social nature. She also included in this category teacher beliefs about how contextual factors such as how weather or exciting events affect student work and behaviour and the nature of the child-teacher relationship. Teacher knowledge in these two categories may well influence primary science teaching.

2.3.5 Knowledge and beliefs about the educational context

Because of this study's focus on the New Zealand context and sociocultural perspective, the knowledge of context domain in the framework for analysis of teacher knowledge has been broadened from earlier frameworks to include social and cultural aspects of the school community and the students being taught. This extension still remains close to Shulman's original idea as his definition of knowledge of educational contexts included knowledge of the "character of communities and cultures" (Shulman, 1987, p. 8).

Knowledge of context formed one of Grossman's (1990) four cornerstones of knowledge. It was a major domain in the frameworks of Abell (2007), Tiplady (2004) and Magnusson et al. (1999). Carlsen (1999) highlighted the importance of this domain by suggesting that it should surround all other knowledges. Hashweh (2005) referred to knowledge of the local education system, which was the general meaning indicated by Shulman (1987) and a meaning applied in this framework, although it has been extended to include a large focus on knowledge of students. Shulman hinted at the importance of students as he included the "workings of the group" and the "character of the community" in his description of this domain (p. 8). Grossman (1990) placed knowledge of students as an overarching feature of knowledge of context. Hashweh (2005) included knowledge of particular students in his framework and Cochran et al.'s (1993) framework has knowledge of students as an area separate to, but equal and overlapping with, knowledge of context. Turner-

Bisset (1999) described this type of knowledge as cognitive knowledge of students which includes knowledge of students' skills and understanding. Cochran et al. described it as including knowledge of students' abilities, learning strategies, developmental levels, attitudes, motivations and experiences.

In the framework for this study, knowledge of the local education system is taken to be New Zealand's education system, since New Zealand's MOE with its national curriculum and governance has the same status as Shulman ascribed to a school district in the United States. The natures of the national and school communities and of the students in the class are further features of this domain of the framework used in this study. Cochran et al. (1993) argued that knowledge of social, cultural and political aspects together with knowledge of the physical environment were part of the educational context. Such knowledge of situation resonates with the sociocultural perspective of this study so this category is therefore subdivided and described as knowledge of the following:

- a) New Zealand school system and structures including governance and financing of schools
- b) Character of the New Zealand community including its social, political, cultural (including bicultural emphasis) and physical environments
- c) Workings and character of the school including its social, political, cultural (including bicultural emphasis) and physical environments
- d) Knowledge of particular students including their social, political, cultural (including bicultural) backgrounds and attitudes together with knowledge of their abilities, learning strategies, ages, developmental levels, attitudes, motivations, experiences.

The relevance of many of these aspects of teacher knowledge for science teaching and learning is apparent; for instance, if a teacher does not know how to manipulate school budgets in order to purchase materials for science activities the nature of science learning could be restricted. The knowledge of students' reading abilities would be of significance in determining the nature of text provided in written instructions or as a source of information. Understanding of students' cultural backgrounds and prior experiences may influence the way science is introduced and which aspects are emphasised. The role of this contextual knowledge in what actually happens as teachers plan and carry out science teaching will be of special interest in this study.

2.3.6 Science content knowledge and beliefs

This domain of teacher knowledge, sometimes referred to as subject matter knowledge, has been a major focus of teacher knowledge frameworks and research (Abel, 2007; Cochran, et al., 1993; Grossman, 1990; Hashweh, 2005; Magnusson et al., 1999; Shulman, 1987; Tiplady, 2004; Turner-Bisset, 1999) and is of particular interest to this study of New Zealand primary teachers given their lack of confidence and background with regard to science (Bull et al., 2010; McGee et al., 2003). Since Shulman's original inception (1986, 1987), this area has been described as comprising two categories largely attributed for their characterisation to Schwab (1964). These subcategories are now outlined and described as they are applied in the framework for this study.

2.3.6.1 *Syntactic knowledge of science*

As Shulman (1987) stated, this category comprises “the historical and philosophical scholarship on the nature of knowledge,” in this case for the discipline of science, “how new ideas are added and deficient ones dropped by those who produce knowledge in this area...the procedures of good scholarship and inquiry” (p. 9).

Hipkins, Barker and Bolstad (2005) suggested that many teachers assume that students are learning about the nature of science as they carry out practical work in science. Teachers' syntactic beliefs and knowledge carry with them assumptions about science teaching and learning that impact on what happens in the classroom (Smith, 1999). As described earlier, primary teachers' views of science as a set of facts found in books or understood by scientists can affect the nature of their teaching or confidence, if such knowledge is seen as too difficult to attain (Appleton, 2006). Shulman (1987) himself states “The teacher also communicates, whether consciously or not, ideas about the ways in which ‘truth’ is determined in a field and a set of attitudes and values that markedly influence student understanding” (p. 9).

The nature of syntactic knowledge that should be developed by students, and therefore what teachers should understand, continues to be debated in the literature. Lederman (2004) argued that criteria used by his research group regarding accessibility for school students, general consensus, and utility for citizenship identified seven aspects of nature of science important to include in curriculum: scientific knowledge is “tentative,...empirically based,...subjective,...involves human inference, imagination and creativity,... and is socially and culturally embedded” (p. 304). Information about the nature of science recently provided on the MOE's teacher support website reflects this list (<http://scienceonline.tki.org.nz/Nature-of-science/What->

[is-the-Nature-of-Science/Teacher-suggestions-Understanding-about-science](#)). Hodson (2009), on the other hand, described the development of a required set of beliefs as “both undesirable and inappropriate to the goal of *critical* scientific literacy” (p. 20), proposing instead that students be engaged in critical debate from which they develop their own warranted beliefs. Ford and Forman (2006), arguing from a sociocultural perspective, proposed a framework for authentic disciplinary learning in science that involved students engaging in “practice as an interplay of roles” played by all scientists: “Constructor and Critiquer of claims” whereby “the ultimate arbiter in community debates is the behaviour of nature” which is “framed, measured and represented” to “support arguments in the public realm about the explanatory accounts under debate” (pp. 4-5).

The nature of teachers’ knowledge in this study is likely to be diverse so the definition of syntactic knowledge used in the framework has been kept deliberately broad. The syntactic knowledge category includes knowledge and beliefs about the nature of scientific knowledge, its philosophy, history, generation, validation and dissemination (Hodson, 2009). The comparison of teachers’ beliefs with the aims for the nature of science strands in the New Zealand curriculum documents will be relevant (Section 1.2). There is some indication that New Zealand primary teachers tended to ignore the integrating strands of the 1993 curriculum (Loveless & Barker, 2000). Hipkins et al. (2005) highlighted problems with this document, suggesting it “contained few direct indications about what the nature of science actually was” (p. 245). They also pointed out difficulties with the Developing Scientific Skills and Attitudes strand focusing largely on fair testing to the exclusion of other forms of scientific investigation. The 2007 document (MOE, 2007) provides more guidance, indicating, for example, that younger students should “appreciate that scientists ask questions about our world that lead to investigations and that open-mindedness is important because there may be more than one explanation” (p. 46).

2.3.6.2 Substantive knowledge of science

Again using Shulman’s (1987) words, this category includes understanding of “the structures of subject matter, the principles of conceptual organisation” (p. 9) a definition shared by Hashweh (2005) who included in this area knowledge of general concepts, principles, relations and topics, as did Turner-Bisset (1999). Hashweh also included two other useful identifiers: knowledge of higher order principles or conceptual schemes and knowledge of approaches, or of different ways of relating topics to other discipline entities (e.g., a molecular approach to biology). Cochran et al. (1993) identified non-target content knowledge as well as topic specific content knowledge as being of use in teaching science. Both these categories have been

included in the knowledge framework for this study to indicate the depth and range of content knowledge exhibited. Tiplady's (2004) constructs of background science content knowledge, developed from secondary and tertiary education, life experiences, and professional development, as science content knowledge used by primary teachers, together with science content knowledge that is developed as required, have been included in the framework as qualifiers for the aspects of content knowledge described above.

2.3.7 Curriculum knowledge and beliefs

For many researchers (e.g., Cochran et al., 1993; Magnusson et al., 1999), this aspect of knowledge is included as part of PCK. The possible breadth of this domain for primary teachers, as described below, necessitated it being kept as a separate domain, as per Shulman's categories (1987). For primary teachers, a wider understanding of curriculum would be expected and could also be of use in science teaching, so knowledge of the wider New Zealand curriculum is included in this framework. Four documents are relevant. *Science in the New Zealand Curriculum* (MOE, 1993a) and the curricula for other learning areas under *The New Zealand Curriculum Framework* (MOE, 1993b) provided direction for teaching and learning when data for the first two cases were collected, although the *New Zealand Draft Curriculum* (MOE, 2006) was available for review by schools and communities during Case 2. Its final form, *The New Zealand Curriculum* (MOE, 2007) was introduced 18 months before data collection for Case 3. The 1993 science document (MOE, 1993a) and the science learning area of *The New Zealand Curriculum* (MOE, 2007) were described in Section 1.2. The 2006 and 2007 versions of *The New Zealand Curriculum* (MOE, 2006, 2007) are each articulated as single documents, with overarching features such as key competencies, values and principles that are expected to influence each learning area and school practice generally. Similarly, the 1993 science curriculum (MOE, 1993a) was part of a wider curriculum framework (MOE, 1993b) that involved the development of essential skills to be included across the learning disciplines. New Zealand primary teachers could bring knowledge of these wider documents and their implications to their teaching of science. Knowledge of both the wider New Zealand curriculum and documentation pertaining especially to science has been included in the framework for this study.

Grossman (1990) found that teachers' knowledge of both vertical and horizontal curriculum influenced teaching decisions. Hashweh (2005) also saw this knowledge as important. Grossman defined knowledge of vertical curriculum as the teacher's

understanding of what students have addressed in lower levels and what they will address as they move on within the discipline; knowledge of horizontal curriculum was defined as understanding of what students are learning at the current level in different subjects. Appleton (2006) suggested that primary teachers sometimes draw on their PCK from other learning areas when teaching science, with both beneficial and limiting effects. New Zealand's curriculum documents suggest outcomes for each level of schooling. Friedrichsen and Dana (2005) found that teachers' goals for their students included those for higher education. Primary teachers' knowledge and beliefs concerning vertical curriculum could influence their science teaching. Both horizontal and vertical knowledge categories have therefore been included in the framework for this study.

The dimension of curriculum knowledge inferred by Shulman (1987) included materials and programmes for the teaching of a particular subject, an aspect that reflects the nature of teaching in the United States. In New Zealand, as described in Section 1.2, the implemented curriculum is the responsibility of the school and teachers, who commonly select teaching resources or develop their own materials to fit the direction of learning suggested by the school or their own preferences. Teachers' knowledge and use of resources is of interest, particularly since introduction of most resources supplied by the MOE has not been well supported (Bull et al., 2010).

Hashweh (2005) considered knowledge of equipment to be part of knowledge of resources which he situated as a subcategory of curriculum knowledge. Appleton (2006) suggested that some primary teachers viewed science as the domain of experts, believing that specialised equipment was required, and did not know how to use everyday classroom equipment for science. Use of both everyday and scientific equipment in science teaching has therefore been included as another category in the curriculum knowledge domain.

2.3.8 Science pedagogical content knowledge and beliefs

Any examination of the development and range of frameworks of teacher knowledge goes inexorably hand in hand with an examination of the development and range of the conceptualisations of PCK. As both Abell (2007) and Kind (2009a) have suggested, research into science PCK is in a state of pre-science; researchers have not yet agreed on definitions or methodologies. It is therefore important to clearly specify the aspects included in PCK in the framework for this study.

Shulman (1987) originally defined PCK as comprising two areas: the knowledge of representations useful for the teaching of the subject and the knowledge of common student conceptions and difficulties with the subject. For some researchers PCK has become synonymous with *all* the knowledge required for teaching (e.g., Fernandez-Balboa & Stiehl, 1995; Tiplady, 2004; Turner-Bisset, 1999). This broad usage of the term PCK is reflected in secondary teachers' identification of elements of their own PCK as described by Lee and Luft (2008). Their list includes knowledge of students, general pedagogical knowledge and content knowledge as being part of their PCK for teaching science. If PCK has been expanded to such a degree to include virtually all of Shulman's original categories then, as Hashweh (2005) and Ball et al. (2008) observed, we do not need the term PCK. PCK would lose one of its most important characteristics, its topic specificity (Hashweh, 2005). While some theorists have argued that all subject knowledge is to some extent pedagogical in nature (McEwan & Bull, 1991), generally PCK has become an accepted construct.

Kind (2009a) identified several empirical studies that include content knowledge as part of PCK. For example, Marks (1990) studied mathematical knowledge of primary teachers and Fernandez-Balboa and Stiehl (1995) studied university lecturers. Both found that content knowledge could not be differentiated from pedagogical knowledge. Inclusion of content knowledge as part of PCK is not helpful in developing the framework for this study as its main purpose is to identify the nature of knowledge teachers bring to their science teaching. However, these findings inform possible outcomes of this study. In reality most models of teacher knowledge sit between the two extremes of integration and transformation, with PCK being given its own status along with the other base knowledge areas (Gess-Newsome, 1999). The degree to which PCK is an entity in its own right or integrated from other domains is discussed in Section 2.4. In the framework for this study PCK occupies a middle ground between all and none, is clearly defined, able to be easily identified in practice or from interview data, and specific to science.

Lee and Luft (2008) and Kind (2009a) provide summary tables of the various knowledges that have been considered part of PCK by different researchers. Both studies confirm that the knowledges most commonly included as subcategories of PCK, apart from content knowledge as discussed above, are: representations and instructional strategies pertaining to the subject; student learning difficulties within the subject (these first two are the original Shulman aspects); subject curriculum knowledge; and knowledge of educational purposes for the subject, sometimes called orientation. This composition of PCK was used in the models of Grossman (1990) and

Carlsen (1999), and is very close to that used by Magnusson et al. (1999) who also added to their model of PCK, subject specific knowledge of assessment. Abell (2007) used an expanded PCK framework combining the models of Grossman (1990) and Magnusson et al. (1999) in her examination of research on teacher knowledge related to science. After an extensive review, Kind (2009a) suggested the model of Magnusson et al. (1999) as the most useful to inform teacher education. Because it maintains a focus on the subject specificity of PCK and links back strongly to Shulman's (1987) original framing, Magnusson et al.'s model of PCK has been used in the framework for this study. This arrangement keeps the focus on the subject specificity of PCK without subsuming science subject matter knowledge. The one exception is that the domain of curriculum knowledge and beliefs has been kept as a separate entity as discussed in Section 2.4.7. The categories of PCK are defined below.

2.3.8.1 Orientation toward teaching science

Grossman (1990) identified "conceptions of purposes for teaching subject matter" as an overarching component of PCK, influencing and influenced by other PCK components, which she defined as "knowledge and beliefs about the purposes for teaching a subject at a particular grade level" and suggested was "reflected in teachers' goals for teaching particular subject matter" (p. 40). Magnusson et al. (1999) renamed this component "orientation to teaching science" (p. 99) while maintaining similar definitions and influence as per Grossman's model. They described different goals for nine different orientations and provided examples from the literature of styles of instruction associated with each. These descriptions provided useful identifiers of both beliefs and practices associated with particular orientations to teaching science and so were included in the framework of this study.

Recently, Friedrichsen et al. (2011) suggested that the definitions of practice associated with the orientations to science teaching described by Magnusson et al. (1999) were problematic and that researchers were using this construct in differing and unhelpful ways. They correctly pointed out that Grossman's development of this construct originated in the beliefs of teachers. By revisiting the literature used by Magnusson et al. they showed that empirical evidence connecting practice with particular sets of beliefs was not strong. They believe there is evidence from the literature to suggest that teachers' orientations shape other aspects of PCK and propose that the component beliefs of this construct be explored further with regard to practice and PCK development. Drawing on literature concerning the nature of teacher beliefs that influence practice, they propose three dimensions through which orientations to teaching science could be usefully explored: beliefs about the purposes and goals of science teaching, beliefs about the nature of science and

beliefs about science teaching and learning. In a personal communication (15 August, 2011), Hilda Borko, one of the authors of the original article by Magnusson et al. (1999), suggested that their original intention was not to “pigeonhole” teachers into one orientation. She believed a teacher’s orientation to be finely nuanced and that exploring the beliefs comprising orientation and their association with particular practice or in influencing PCK development, as suggested by Friedrichsen et al. (2011), matched the purpose for which the article was written: to consider the nature of PCK for science teaching, which at that time had not been a major focus of research. Problems in this study with the duality of Magnusson et al.’s construction of orientations as a set of beliefs and as a categorisation of practice are discussed in Chapter 8. The beliefs comprising orientations to science teaching exhibited in each case, according to Friedrichsen et al. (2011), are summarised in Section 8.2.2. Prior to that point, orientations to teaching science are used as defined in the article by Magnusson et al. (1999).

2.3.8.2 Knowledge of science instructional strategies

This aspect of teacher PCK expands on the category of representations useful for science teaching by Shulman (1987) and is part of the models for PCK of Abell (2007) and Magnusson et al. (1999) who included knowledge of science specific strategies useful for any topic or relating to a specific topic. Treagust (2007) suggested instructional strategies includes use of demonstrations designed either to motivate or to increase student cognitive involvement such as the Predict, Observe, Explain strategy (Palmer, 1996) and may include interactive computer programmes. He also included use of explanations which “connect between and among pieces of information” (Treagust, 2007, p. 376). Representations, analogies and models were instructional strategies examined by Treagust (2007). He found these could be used in two ways: to assist with student understanding of a given science concept and to promote syntactic understanding of science, where they are discussed, compared, created and evaluated as to their usefulness in explaining a situation, that is, in ways commensurate with their use in science. Coll, France and Taylor (2005) found that use of models provided opportunities for students to learn about the nature of science as well as learning science content. Finally, Treagust (2007) included as an instructional strategy use of scientific discourse types including argument or debate on a variety of theories with use of evidence. Osborne, Erduran, Simon and Monk (2001) proposed the use of argument that draws on evidence as a way of learning both scientific content and culture. Keogh, Naylor and Downing (2003) found that children’s scientific argumentation skills developed from using concept cartoons and puppets. Solomon (2008) suggested that some teachers would not include such

strategies as they do not think science is a knowledge base that can be questioned, indicating limitations in their syntactic knowledge.

All four forms of instructional strategy described above have been included in the framework for this study.

Appleton (2002, 2003, 2006) described what he called activities that work: practical science activities from past experiences or passed on by colleagues that address required content, contain science content known to the teachers or explain new content for them, involve and are enjoyed by students, are manageable in the classroom, and have predictable outcomes. He found that for primary teachers these activities were a form of PCK (2003). Since this study pertains to primary science teachers, activities that work form a sub-category of instructional strategies so they are recognised if they are used as a form of PCK.

Research into the social, historical and philosophical aspects of science knowledge has placed an emphasis on the importance for teachers of understanding syntactic aspects of science content knowledge and particularly on ways to convey this to their students (Solomon, 2008). Teachers need PCK for teaching syntactic aspects of scientific content (Abd El-Khalick & Lederman, 2000; Hipkins et al., 2005; Hodson, 2009). Smith (1999) suggested that such syntactic PCK included knowledge of ways to elicit children's explanations and understanding that such elicitation is important because it enables children to hear alternative explanations for the same event and evaluate them in light of their own, thereby contributing to a more realistic experience of the nature of science. She included questioning skills useful in eliciting explanations as part of syntactic PCK along with ways of encouraging and managing the interplay of ideas and evidence in the social community of the classroom in order to progress toward an agreement about the usefulness of different explanations. Finally, Smith included in syntactic PCK recognition of opportunities where syntactic issues could be raised and explored, for example production of anomalous data in children's science investigations. Syntactic strategies form part of the framework of PCK for this study as a sub-category of instructional strategies.

2.3.8.3 Knowledge and beliefs about science assessment

This sub-category appeared in the frameworks of Abell (2007) and Magnusson et al. (1999) who suggested two aspects within the sub-category included in the framework for this study: dimensions of science learning to assess and methods for assessing science learning.

2.3.8.4 Common student preconceptions and difficulties

This final aspect of teacher knowledge was indicated as a significant aspect of teacher PCK by Shulman (1987) and was included in the frameworks of Abell (2007) and Magnusson et al. (1999). Shulman (1987) indicated that this category included knowledge of common naive conceptions and aspects students find easy or difficult for a particular topic. MOE science resources such as the *Building Science Concepts* series (e.g., 2002) sometimes include this information in teacher notes. Given the lack of professional support for science, teachers in this study may not know to access such information in these resources. A subdivision of knowledge within this area suggested by Cochran et al. (1993) is knowledge of the prior conceptions of the topic for the group being taught. Knowledge of both general preconceptions, difficulties and those particular to the group being taught would be important particularly for conceptual change approaches to science, and so are included in the framework for this study.

2.3.9 The teacher knowledge framework for this study

The previous sections have examined the research literature concerning the nature of knowledge for science teaching to develop a framework to support analysis in this study. The intention behind the development of this framework has been to design a wide net in which to capture the full range of teacher knowledge that may impact on classroom science teaching and yet make the description of each domain, category and subcategory sufficiently detailed to facilitate its identification. The development of this framework has therefore drawn on a wide range of the teacher knowledge research literature with respect to teaching in general, primary teaching and, in particular, the teaching of science. The framework as developed above is presented in Chapter 3 in describing the methods used for analysis (Table 3.3 p. 65).

2.4 Development of knowledge needed for science teaching

This section reviews the literature concerning development of the knowledge needed for science teaching. While a main focus of this study is to identify areas of knowledge on which primary teachers draw for their science teaching, another question raised by the sociocultural perspective applied to this study was how highly regarded generalist primary teachers of science develop the knowledge they need to teach science. The framework developed in the previous section highlights two domains of knowledge specific to science: science content knowledge and science PCK. The literature concerning development of knowledge in these two domains is examined below.

2.4.1 Development of science content knowledge

As indicated in Section 2.3.6, there are two types of science content knowledge forming this domain: syntactic knowledge of science and substantive knowledge.

2.4.1.1 Development of syntactic science knowledge

Teachers' development of syntactic understanding, particularly with regard to the nature of science, has been the focus of much research over many years. This overview summarises outcomes of recent major analyses of research in this area.

Abd El-Khalick and Lederman (2000) cited a range of studies examining between them a broad range of variables. They found that teachers' background experience is a poor predictor of nature of science understanding. Lederman (2004) suggested that one approach to development of syntactic knowledge has been to assume that teachers already have it and provide no professional support. Another strategy for syntactic knowledge development has been to teach the history of science, outcomes of which have been inconclusive (Lederman, 2004). Abd El-Khalick and Lederman found that the most successful form of intervention has been where instruction is explicit and specifically focussed on developing syntactic understanding. More recently, studies have focussed on whether development of syntactic understanding is more effective when integrated into a topical context. Khishfe and Lederman (2006) found both to be equally effective. Heap (2006) found de-contextualised activities effective in focussing New Zealand pre-service primary teachers' attention on syntactic aspects of science. Clough (2006) suggested both contextual and de-contextualised activities are necessary, arguing for a conceptual change approach to syntactic teaching. Hodson's (2009) extensive review supported findings concerning the need for explicit teaching but highlighted that opportunities for discussion and reflection, as provided in Heap's study, are significant factors in knowledge development. These aspects were present in a prolonged programme of professional development involving teacher participation in inquiry explicitly designed to illustrate aspects of the nature of science, as well as critical reflection on curriculum resources, monthly workshops on strategies for teaching the nature of science, and individualised classroom support (Hanuscin, Lee & Akerson, 2011). The participating elementary teachers' syntactic knowledge improved considerably and they began to emphasise syntactic aspects of science in their teaching.

Hodson (2009) highlighted research showing that a range of factors impact on whether a teacher firstly adopts and then implements teaching about the nature of science. Syntactic and substantive content knowledge were important, but

recognition of the importance of teaching about the nature of science was critical. Like Smith (1999), Hodson (2009) contended that teachers who view science as fixed knowledge will see no need for teaching nature of science. Hipkins et al. (2005) similarly suggested that a teacher with a sociocultural view of learning as a cultural process may be more likely to embrace sociocultural aspects of science than a teacher whose view of learning focuses on changes in knowing.

This summary of research shows that development of syntactic knowledge that reflects accurately the nature of science is a complex and deliberate process that teachers are unlikely to make unaided. In New Zealand there has been little professional support for implementation of science curricula that include syntactic outcomes. Findings in the literature emphasise the need for investigation into the nature of knowledge that New Zealand primary teachers bring to their science teaching and how, and if, they develop syntactic knowledge to support curriculum implementation.

2.4.1.2 Development of substantive science knowledge

Abell (2007) summarised research into science content knowledge and teacher effectiveness, finding the evidence supports a positive relationship between subject matter knowledge and effective teaching. Many studies implied that other types of knowledge were also involved. Borko and Putnam (1996) reported that novice and experienced teachers often lacked the flexible knowledge needed to respond to student thinking. Hattie's (2009) synthesis of meta-analyses indicated there was little evidence that teacher knowledge had much effect on student achievement, but this synthesis did not pertain particularly to science. Studies of primary teachers showed that poorer classroom practice resulted from weaker content knowledge, for example, Newton and Newton (2001) found that teachers with weaker science backgrounds interacted less, asked fewer questions, and lectured more. Multiple studies have examined primary teachers' understanding of specific science concepts. Findings show that teachers tend to display similar misconceptions to those found for students (Abell, 2007).

One response to poor primary teacher science content knowledge has been to increase science content in initial teacher preparation courses (Osborne & Simon, 1996). Official reports suggest significant improvement in the numbers of teachers feeling prepared to teach all elements of the science curriculum and perceiving no impediments to the teaching of primary science (Sharp et al., 2009). A collection of research has resulted in investigating primary teachers' subject matter knowledge through structured interviews and questionnaires (e.g., Summers, Kruger, Mant &

Childs, 1998). Traianou (2006) argued that such measures of teacher content knowledge did not adequately represent teachers' ability to address classroom content knowledge issues. Children's questions and investigations often occurred in contexts much more complex and scientifically ambiguous than those investigated in such research, requiring both contextual and pedagogical expertise to solve.

Despite multiple studies showing poor standards of content knowledge, few studies could be found investigating how primary teachers develop science content knowledge. Arzi and White (2008), in a 17 year longitudinal study of changes in secondary science teachers' content knowledge, identified that school science curriculum materials were a strong source and organizer of teachers' content knowledge. Abd El-Khalick (2006) reported opportunities to reflect on subject matter in conjunction with teaching experience changed the organisational structure of secondary teachers' content knowledge. Smith and Neale (1991) reported that elementary teachers' substantive knowledge improved considerably for a science topic following prolonged intensive professional development that included studies of students' conceptual knowledge, activities concerning teachers' own knowledge regarding the topic, and planning and teaching students.

Appleton (2003, 2006) found that primary teachers developed content knowledge from activities that work where such knowledge was included. Similar findings are reported by Beyer and Davis (2009) and Schneider and Krajcik (2002) in investigations concerning effectiveness of educative elementary science curriculum materials; teachers reported building understanding from information regarding students' misconceptions as well as directly from content knowledge provided in these materials. Davis (2004) studied a pre-service elementary teacher's development of knowledge for science teaching as she drew on curriculum materials to plan science lessons. She found the teacher identified weaknesses in her content knowledge, made links between ideas, reconciled conflicts and distinguished between concepts, drawing on existing knowledge and linking to real-world experiences useful for teaching, often appropriately but sometimes inappropriately.

Traianou's (2006) longitudinal case study of an experienced primary lead teacher of science found that the teacher was able to identify scientific ideas she did not understand and address them. She had developed ways to approach issues of her content knowledge as they arose. Sometimes she did this alone or discussed concepts with other staff, and sometimes she involved the children so that together they developed their understanding of a concept. She therefore was continually

developing not only her content knowledge, but also a repertoire of ways to approach problems to do with content knowledge. Kind (2009b) reported that pre-service teachers teaching outside specialism used a wide range of sources to locate content knowledge, including experienced teachers, whereas those with deeper content knowledge experienced dilemmas over selection of content. Tiplady (2004) found that experienced New Zealand primary teachers she interviewed consciously set out to develop their science content knowledge if they felt it was inadequate for a topic they were preparing to teach. They did background reading and found appropriate resources. As with Traianou's study, collegial support was seen as a positive contributing factor to content knowledge development. The teachers' beliefs about science as a "hands-on" subject strongly affected their teaching decisions. Tiplady found teachers drew on two types of content knowledge: background content knowledge from secondary and tertiary education, life experiences and professional development, and content knowledge that was developed as required.

The issue of science content knowledge has not been addressed by increasing time spent on science in initial primary teacher education in New Zealand. Anecdotally it appears that this time is actually declining (B. McIntyre & H. Trevethan, personal communication, May/June, 2009). The above findings suggest that some New Zealand primary teachers expect to and do develop their own content knowledge for science (Tiplady, 2004). This study will further illuminate these findings by exploring the nature of content knowledge that is developed and used. Davis (2004), Traianou (2006) and Tiplady (2004) all suggest that planning for teaching draws together other teacher knowledge useful for science teaching as well as content knowledge. The literature concerning the development of science pedagogical content knowledge is discussed next.

2.4.2 Development of pedagogical content knowledge

The nature and development of PCK has been debated ever since Shulman (1986, 1987) first proposed it as a form of teacher knowledge. Gess-Newsome (1999) describes researchers as working from a continuum of frameworks of teacher knowledge with regard to PCK. At one end there is an integrative model where PCK does not exist independently and the knowledge special to the teaching of a subject is best explained as the intersection of base knowledge constructs. At the other end of the continuum is a transformative model in which PCK results from the transformation of base domains into a new form of knowledge. She suggested the analogy of a mixture versus a compound to describe the difference: in an integrative model (the mixture) the parent domains can be readily seen in justifications for

planned and “in-action” teaching decisions. In a transformative model (the compound) the parent domains are less immediately obvious and traceable only through thorough analysis. In an integrative model, an expert teacher effectively integrates well-developed knowledge from the base domains as needed. They enrich and develop the base domains as a result of reflection on teaching. In a transformative model teachers justify teaching decisions within PCK and without reference to the base knowledge areas. While this model recognises the value of a synthesised knowledge for teaching, it also raises the question of exactly what PCK *is* and what would make it different from the base knowledges. Gess-Newsome suggested such knowledge would be contextually bound, making generalisations across different teaching situations difficult. Integration may explain some of the difficulty described in trying to document examples of science teachers’ PCK (Loughran, Milroy, Berry & Gunstone, 2001). These researchers found that every teaching situation is different and therefore what could be observed regarding PCK varied. In order to describe examples of PCK relating to a specific science topic, they found they needed to describe elements of the context in which it occurred. They also listed a variety of other teacher knowledge areas that they suggest interact with PCK, including subject knowledge and knowledge of the students.

Hashweh (2005) described a model of PCK development that regards PCK as a set of teacher pedagogical constructions (TPCs). He proposed that these were topic specific and resulted from an inventive process that is influenced by the interaction of knowledge and beliefs from the base teacher knowledge domains. TPCs are developed mainly through planning, but also the interactive and reflective phases of teaching. This model fits with work in documenting PCK for different science topics (Loughran et al., 2001; Loughran, Mulhall & Berry, 2004). The process of developing TPCs appears to be an integrative one but becomes a transformational process as various TPCs are stored collectively to form PCK.

Appleton (2006) proposed a model of PCK development for primary teachers. While he cited transformative examples where primary teachers have used their existing knowledge to create new knowledge that can be conveyed to other teachers as an entity, he also provided examples of integrative PCK, where teachers made on the spot decisions to respond to children’s line of conceptual thinking and organised relevant spontaneous investigations. Central to his model were activities that work (Appleton, 2002, 2003). He described how teachers new to science teaching or experienced teachers teaching a new topic relied heavily on these and used them to share and discuss their teaching with other teachers. When shared, these took on

the form of a narrative that can be tried and adapted by other teachers. Resources that describe activities are an example of this type of narrative. Appleton suggested teachers used their pedagogical knowledge, knowledge of students and existing science PCK to transform these activities into their personal PCK. This happened in a progression that begins with the identification of an activity, which then undergoes a transformation process through interaction with other forms of the teacher's knowledge, filtered and shaped through the teacher's orientation to teaching and learning. Activities become PCK for planning, then become experiential PCK at the point where the activity is implemented. It is then transformed into a form that can be communicated to others (the narrative) and becomes part of the teacher's existing PCK ready for informing the development of further PCK. General pedagogical knowledge appeared important in filling in the gaps in activities that work and turning them into useful PCK. Existing PCK and content knowledge also contributed to the development of new PCK. Appleton saw teacher confidence, although not a knowledge domain, as an important factor in developing PCK: if teachers were not confident enough to try teaching a science activity they could not begin to develop PCK. Kind (2009b) also described a group of confident teachers who identified the importance of locating appropriate activities rather than worrying about inadequate science content knowledge.

Appleton's (2006) model is supported by longitudinal research of a teacher over her first ten years of teaching by Mulholland and Wallace (2005). They found that the teacher was able to develop her science content and PCK largely on the basis of curriculum resources: activities that work. These researchers also emphasised the importance of pedagogical knowledge in this process; the teacher did not begin to progress in her teaching of science until she had developed a strong pedagogical knowledge, even though she had a strong knowledge of the purposes of science education and positive attitude to science teaching from the beginning of her teaching career. Her pedagogical knowledge grew with her experience in the classroom and as this grew it began to allow her specific science teaching knowledge to develop as she had more confidence to manage practical activities and try new science approaches. This supports Appleton's proposal that general pedagogical knowledge supports implementation of activities that work in leading to PCK development.

Smith (1999) found in working with primary teachers, that initial exposure to the ideas and explanations of children was a worthwhile entree into development of both substantive and syntactic PCK. Once they had worked with children in eliciting their explanations for a phenomenon, teachers began to explore their own understandings

of the phenomenon in both practical and theoretical ways. Just as a focus on children's explanations had facilitated her personal development of new activities to facilitate children's understanding of scientific concepts, new ways of investigating and exploring ideas, new representations, and her understanding of common children's conceptions had been refined and expanded, so it was for the teachers she worked with. They developed significant PCK, although not all did so easily. Schwartz and Lederman (2002) suggested that key elements for the development of syntactic PCK by teachers included syntactic and substantive content knowledge and knowledge of pedagogy, but also an intention and belief that they could teach about the nature of science and that their students can and should learn about it. Teacher discussion was found to be important in developing both PCK and associated content knowledge by Daehler and Shinohara (2001). Hanuscin et al. (2011) considered the syntactic PCK development of elementary teachers who had developed strong syntactic science content knowledge and teaching strategies through prolonged professional development. They found that the teachers drew on their content knowledge, general pedagogical knowledge, and knowledge of their context in developing syntactic PCK. The teachers' orientations to teaching science, categorised from Magnusson et al. (1999), changed from an activity to an inquiry orientation during the professional development. Curriculum knowledge was drawn on little, largely because there were few resources to support syntactic science. These researchers found a need for educative materials to support teachers with syntactic teaching.

The debate as to whether or not subject knowledge is transformed into specialist knowledge for teaching and how this might occur is ongoing (Abell, 2007; Gess-Newsome, 1999; Kind, 2009a). Integrative models do not explain how PCK results and transformative models imply a mechanism exists (Kind, 2009a). Shulman (1987) described a process of pedagogical reasoning wherein the teacher takes their content knowledge and "makes it ready" (p. 14) for effective instruction. Pedagogical reasoning was seen as a cycle that involved comprehension by the teacher of the original content, including the subject matter structures, followed by transformation by the teacher of that content into forms that effectively represented the content in ways that reflected the nature of the students. There then followed instruction, evaluation and reflection to complete the cycle arriving at new comprehension of both the nature of the content and also of the students and the pedagogical process. In this way, although not explicitly stated, Shulman suggested that by engaging in reflective practice teachers may produce for themselves new pedagogically useful knowledge. Abd El-Khalick (2006) found opportunities for reflection affected teachers' knowledge development and proposed that PCK

develops as a result of interaction of other knowledge domains. He suggested that evaluation and reflection required knowledge of content, aims and purposes. PCK development was therefore dependent on teachers' knowledge in other domains and developed as "teachers think and act on their knowledge for the purpose of teaching it" (p. 26).

Kind (2009a) summarised her review of literature concerning development of science PCK as consistently showing that it develops over time and for new teachers that classroom experience, strong content knowledge, and emotional attributes such as confidence were involved. For more experienced teachers, content knowledge and PCK appeared less separate. She found that the literature suggests a preference for integrative models. Development of PCK from other base areas seems particularly relevant when examining the knowledge of primary teachers who are continually approaching new science topics for which they have little subject matter knowledge or existing PCK, but who may have strong bases of other types of teacher knowledge. Examining the contribution of the different knowledge bases and the interplay between them apparent in teaching may shed light on the development of PCK. Tiplady (2004) found the teachers she studied had a strong knowledge of their students and their interests that they integrated easily, when selecting tasks to challenge students' ideas, with the knowledge of content they developed, their pedagogical knowledge and knowledge of the school context. Magnusson et al. (1999) postulated that the domains of knowledge may unequally influence the development of PCK. For example, in a topic for which a teacher has relatively weak subject matter knowledge but for whom pedagogical knowledge is dominant, the transformation of that knowledge into PCK will be influenced mainly by their pedagogical knowledge. Influences on PCK development and mechanisms of transformation or integration are an important consideration in this study.

2.5 Development of a framework of analysis for identification of sociocultural teaching approaches

The main purpose of this section is to review the literature concerning sociocultural theories of learning to develop a framework of analysis for use in this study that supports identification of sociocultural teaching approaches. Further, the opportunities for science learning through sociocultural approaches described support the reasons for selecting a sociocultural perspective in this study that were given in Section 1.3.

The origins of a socially mediated and located view of knowledge construction appeared in the early twentieth century, but its relative lack of rigour at that time meant it was largely ignored in favour of more prestigious laboratory-based psychology that focused on individuals (Salomon & Perkins, 1998). The publication of the work of Lev Vygotsky in the 1960s together with a re-examination of the significance of social interactions in Piaget's work and a growing recognition of the social, historical and cultural influences on learning from the fields of anthropology and sociology focused attention on the socially mediated and situated nature of cognition (Barker, 2008b; Bell, 2005a; Salomon & Perkins, 1998). Wertsch (1994) perhaps best explains the nature of a sociocultural perspective: "In this view one cannot provide an account of human action without taking its cultural, institutional, and historical setting into account. On the other hand, such settings are produced and reproduced through human action" (p. 203).

2.5.1 Sociocultural theory and classroom practice

As Lemke (2001) suggests, there is no common picture of an ideal sociocultural science classroom as there may perhaps be for a more constructivist conceptual change approach to learning. Anderson (2007) similarly points out with regard to science teaching, it has been difficult to "translate sociocultural ideas about teaching into prescriptions for reproducible practice" (p.19). Descriptions of sociocultural science teaching practice in the literature often focus on just one aspect of sociocultural theory. For example, in identifying approaches to science education, sociocultural theory was cast as useful for working with multicultural and indigenous classrooms (Pendretti & Nazir, 2011), but descriptions of practice reflect only enculturation and do not consider features such as distributed cognition that also characterise sociocultural theories. Barma (2011) provides a useful summary of the general features of some recent socioculturally anchored science education approaches, but the article was developed after analysis in this study was completed. Many of the general features she describes are included in the framework developed below, but were less detailed than required for this study.

The features of sociocultural theory can be used as identifiers of sociocultural approaches to learning. Eames (2003) used the features of sociocultural theory to conceptualise socioculturally framed learning in co-operative student work placements. A similar approach has been used here for science teaching and learning in primary classrooms. The features of the theory are described and used to develop a framework for analysis of practice. Where they have been identified, examples of classroom practice from the literature are discussed.

Sociocultural theories of learning were derived largely from studies of the workplace (Lave & Wenger, 1991; Wenger, 1998) and participation in cultural communities (Rogoff, 2003). Lave and Wenger (1991) did not see classrooms as authentic communities of scientific practice. Mercer and Littleton (2007) point out that classrooms are not workplace learning situations, nor do they replicate the social and cultural situations where children learn to become cultural participants in their families and wider cultural and social settings. Barab and Duffy (2000) suggest that classrooms create practice fields. These are contexts in which learners can practise the kinds of activities that legitimate participants such as scientists use. Practice fields are separated in time and setting from the real field and comprise authentic activities carried out in an environment and circumstance as close as possible to that of the legitimate practice. Practice fields are a concept applied to generation of computer learning environments but are a useful concept for considering sociocultural teaching approaches in classrooms as in this study.

The degree to which students in classrooms learn and work in authentic contexts and are engaged in genuine practice can be argued, but the features of sociocultural theory facilitate the identification of sociocultural teaching approaches with regard to science. Features of sociocultural theory as it applies, or could apply, to classrooms are provided in the following sections.

2.5.2 Learning as socially mediated action

The first key feature of sociocultural theories of learning is that learning involves socially mediated action (Bell, 2005a; Wertsch, 1991). Vygotsky's notion that any function in children's development appears first on the social plane and then on the psychological plane and that internalisation transforms the process, changing its structures and functions, is significant in sociocultural theory and perhaps best illustrates the emphasis on socially mediated action (Wertsch, 1991). In other words, children see or are involved in actions before they internalise and transform them for their own use. Mediated action is a human action that employs mediational means: technical or material tools, such as computers, or psychological tools, such as language, signs, gestures and symbols (Bell, 2005a). Tools can also be seen as procedural or conceptual and as such are products of the cultures or communities that create them and the ways in which they are used: "a set of shared social meanings, which its members use to interpret and negotiate their interpretations with one another, thereby enabling them to continue to act successfully in the activities of that community" (Traianou, 2006, p. 836). Salomon and Perkins (1998) describe

several forms of active social mediation that relate well to classroom situations, which are described in the following sections.

2.5.2.1 Active social mediation of individual knowledge construction

The first form of socially mediated action is where an individual or a team assist an individual to learn (Salomon & Perkins, 1998). It may occur through provision of information such as instructions or demonstrations or through provision of feedback, approachable tasks, encouragement, or scaffolding of the individual's actions with tips and hints. This form of social mediation is probably most akin to the social constructivist approach to learning, which focuses on the individual as the recipient or acquirer of learning rather than seeing the individual as part of a community, a more sociocultural view. However, a community facilitating an individual's participation in its practice is a sociocultural perspective; the emphasis is on increasing participation rather than acquiring knowledge. The borders between social constructivism and sociocultural views are not clearly defined and present more as a continuum (Barker, 2008b).

2.5.2.2 Social mediation as participatory knowledge construction

Participatory knowledge construction represents learning less as knowledge acquisition by an individual and more as participation in a social process of knowledge construction. In this means of mediation the team or individual coaching of an individual are seen as an integrated and situated system where interaction is "socially shared vehicles of thought" (Salomon & Perkins, 1998, p. 4) thus the learning is jointly constructed and owned, i.e., distributed over the participating group. All those involved will have learned or been changed in some way through participating in the action.

2.5.2.3 Social mediation by cultural scaffolding

In some situations the learner is not in direct contact with another person, but the learning is mediated by cultural artefacts or tools. Tools are a means with which to act upon the world as well as "cognitive scaffolds that facilitate such action" (Salomon & Perkins, 1998, p.11). Tools are also culturally and historically situated, having embedded in them the assumptions and ideas associated with the community that produced them. Thus as the learner interacts with the tools they also interact with the culture that produced them; social mediation occurs as the learner actively engages with them. Wenger's (1998) complementary concepts of participation and reification are relevant here. His definition of reification roughly equates with the cultural tools or artefacts described above. He speaks of the inherent dangers of reification; knowledge of an idea can lead to the illusion that it is

fully understood. In both the formulation and interpretation of reifications such as books or written recordings of practice, meaning can be potentially lost or potentially expanded. Wenger suggests that participation can fix confusions caused by misunderstandings in reification, and reification can fill gaps where participation is not possible. In social mediation by cultural scaffolding the participation in the actual community that created the tools is limited, and thus there is a danger of misinterpretation.

2.5.2.4 *The social entity as a learning system*

When a system learns, the focus is not on one agent or group mediating the learning of another; the collective system learns as they interact together. Salomon and Perkins (1998) provide examples of sports teams or business organisations that learn how to interact more effectively together in order to achieve a common goal. This could be applied to classrooms where as a result of interaction the class or small group learns better how to engage in an activity as a whole. By deliberately cultivating cooperative and collaborative classrooms and group work where children's ideas and contributions are valued and student participation and ownership of tasks and learning encouraged, the class as a whole learns to function as a learning community together, including the teacher (Rogoff, Matusov, & White, 1996).

Mercer and Littleton (2007) describe how a teacher provides opportunities for the student and teacher to stay attuned to each other's changing states of knowledge where the status of the learning is constantly negotiated through dialogue. They term this the Intermental Development Zone (IDZ), a more active version of Vygotsky's zone of proximal development, stating that it represents "a continuing state of shared consciousness maintained by a teacher and learner, which is focused on the task at hand and dedicated to the objective of learning" (p. 21). They contend that effective teachers maintain a collective IDZ.

2.5.2.5 *Learning to be a social learner*

The final two forms of learning outlined by Salomon and Perkins (1998) are not so much socially mediated actions, but rather processes learned *through* socially mediated action: the content of the learning. Because they relate to the socially mediated actions described above and because they may form part of primary teaching practice they are included here.

Learning to be a social learner focuses on the task of learning to learn. Metacognition is a focus of the current New Zealand curriculum where for example the key competency of "thinking" emphasises the use of metacognitive processes to

“make sense of information, experiences and ideas” and “managing self” is associated with students “seeing themselves as capable learners” (MOE, 2007, p. 12). Through learning, learners learn about learning as a process. Salomon and Perkins (1998) point out that in socially situated learning, learners find out how to actually participate in and benefit from social learning, for example learning when and how to ask questions, how to ask for help, or how to join in reciprocal learning relationships. Again, these processes are applicable to the classroom, where the relevant behaviours may be highlighted and given importance by a teacher intentionally focused on socially mediated learning.

2.5.2.6 Learning social content

The final form of socially mediated action described by Salomon and Perkins (1998) is learning social content. The aspects described in the previous section relate to an individual learning to function within a group. This form of social mediation describes the learning involved in functioning *as a group*: allowing different group members’ views to be heard, collaborating to reach decisions, or taking collective actions. Again this aspect relates closely to the current New Zealand Curriculum through the key competency of “relating to others” which includes learning to “listen actively, recognise different points of view, negotiate and share ideas” (MOE, 2007, p.12).

In outlining forms of socially mediated action, other key aspects of sociocultural theory have also been highlighted: learning as a situated and participatory activity and the distributed nature of cognition, the idea that knowledge does not just reside inside the head of an individual but is distributed to various extents at different times across the members of the learning community (Bell, 2005a; Lave & Wenger, 1991; Rogoff, 2003). Socially mediated action occurs within all situated and participatory activity. The descriptions above can be used to identify socially mediated actions and have been incorporated as part of the framework for identification of sociocultural teaching approaches in this study. Without socially mediated action it is unlikely that situated and participatory learning in communities of practice would occur. The nature of communities of practice and the cultural nature of learning is discussed next.

2.5.3 Communities of practice and the cultural nature of learning

Wenger (1998) sees learning occurring through changing participation and identity transformation in a community of practice. There are three dimensions to a community of practice: joint enterprise, mutual engagement, and shared repertoire. Communities of practice are not self-contained; they exist in wider social and historical contexts. Wenger describes practice as the source of coherence of the

community: “communities of practice provide a privileged context for the negotiation of meaning” (p. 85). He points out that communities are not necessarily harmonious, collaborative, or emancipatory; they may develop in ways that allow response to new situations but they may also develop in ways that prevent such response. Communities of practice, according to Wenger (1998), develop through participation and development of shared understanding as to the nature of the practice. He defines competent membership of a community of practice as:

1. Mutuality of engagement: the ability to engage with other members, responding in kind to their actions.
2. Accountability to the enterprise: the ability to understand the enterprise of the group enough to take some responsibility for it and contribute to its pursuit.
3. Negotiability of the repertoire: the ability to use the repertoire (experiences of meaning) of the practice enough to be able to engage in it. A competent member needs to be able to recognise the practice and then by both capability and legitimacy, be able to make this history newly meaningful.
(p. 137)

It is by its practice that the community determines what it means to be a competent participant. Participation in practice constitutes learning and understanding (Barab & Duffy, 2000).

Communities of practice are intrinsically related to culture. Rogoff (2003) defines communities as “groups of people who have common and continuing organization, values, understanding, history and practices” (p. 80). Variation within a community amongst individuals is natural; participants do not behave in identical ways or hold identical views. “It is the common ways that participants in a community share (even if they contest them)” that are regarded as culture (Rogoff, 2003, p. 81). Primary classrooms can be seen as communities of practice that come to share a common culture. Similarly, scientists can be viewed as sharing a community of practice with its own culture, organisation, shared values and accepted ways of doing things. Students in classes can be viewed as coming with their own set of practices, values and understandings developed from being active participants in their family’s social and cultural communities. As Rogoff (2003) states: “People develop as participants in cultural communities. Their development can be understood only in the light of the cultural practices and circumstances of their communities, which also change” (p. 4). A sociocultural view therefore goes beyond earlier theories of learning to emphasise the importance not just of the relevant concepts that a student brings to a learning situation, but aspects of their identity and culture: who they are as human beings, how they behave and interact with their surroundings and others (Barker, 2008b). New Zealand classrooms are increasingly multicultural. There is also the added layer of the bicultural nature of New Zealand’s heritage. Much research and thought

is being given to ways to engage more effectively Māori students who are in English medium education (Alton-Lee, 2003; Bishop, 2003). Teachers have been perceived as facilitators of border crossings, or brokers, between communities of practice (Aikenhead, 1996; Barker, 2008b). Primary teachers can be seen to be assisting their students to make this border crossing into the realm of science as well as into many other such communities. Teachers who understand the nature of the cultural experiences of their students and their significance may be more able to facilitate students' participation in other communities of practice.

Rogoff (2003) introduces the dynamic nature of the interrelationship between the individual and the communities in which they participate. Just as individuals develop and transform as they participate in and contribute to cultural practices and use cultural tools, those practices and tools are developed and transformed by the different individuals that participate in them over successive generations. So the students who comprise a class or group develop the practices of that class as well as being changed by their participation in them. As described in Section 1.3, Traianou (2006) explains how situated participation in communities also prepares individuals for new situations, allowing dynamic transfer of activity and meaning through linking and applying tools across communities and time.

2.5.4 Learning as situated and participatory activity

The culturally and historically situated nature of participation is a feature of sociocultural learning theories (Wertsch, 1994). The following sections describe sociocultural views of learning and how these may apply in classroom situations.

2.5.4.1 Learning as participation in communities of practice

Learning as a situated and participatory activity is an idea developed by Lave and Wenger (1991) from their studies of apprenticeship situations. Learners are seen as moving toward full participation in communities of practice. Learning occurs through participation in the activity of the community. Lave and Wenger describe legitimate peripheral participation as the way apprentices are allowed to participate in the basic activities of the community and over time increase their participation by being involved in more complex activities. The characteristics of this learning are then that it is situated in the context of authentic activities and develops from participation in the practice of the community. As Brown, Collins and Duguid (1989) suggest, this situation of learning in authentic contexts enables both the development of the use of cultural tools and the world in which they are used. It may begin with simpler real tasks that are gradually integrated into the more complex aspects of practice. Novices have opportunities to observe real expert practice and have interaction with expert practitioners.

In the practice field of the classroom, authentic practice may be closely replicated through students being engaged in authentic activities. Authentic activities are the “ordinary practices of the culture” (Brown et al., 1989, p. 34). For science this could be asking questions, carrying out investigations using a variety of approaches and solving methodological problems, gathering evidence, developing reasoned explanations that account for evidence and communicating findings (Hodson, 2008; Lee & Butler, 2003). Edelson (2003) contends that students also need to experience the attitudes of uncertainty and commitment that are important in sustaining scientific investigation and to appreciate that the nature of interaction in scientific communities is a mix of “co-operation and competition, agreement and argumentation” that is characteristic of all human activity (p. 319). Barab and Duffy (2000) suggest that such opportunities arise from student ownership of inquiry when dilemmas or problems are “ill structured” (p. 32), as in investigating real situations, so that students need to draw on their own resources to solve them. Such student owned investigations of the natural world are regarded as authentic science investigation in this study.

A further implication for classrooms from understandings of communities of practice is the nature of the joint enterprise: the shared nature of the common goals and endeavour of the community (Wenger, 1998). Distribution of tasks so that groups or individuals are contributing to an overall class goal is one way that this aspect of a community of practice may manifest in classrooms. Mercer and Littleton’s (2007) concept of the maintenance of a collective IDZ is relevant. It provides a way of keeping current shared goals and the common endeavour of the class community of practice at the forefront of the class consciousness.

Another feature highlighted by Lave and Wenger (1991) was that novices were not expected to start with managing the mature practice of experts; they often began with simpler tasks in a staged manner. There are differences between the practice of scientists and the practice of school children (Lee & Butler, 2003). Differences include experience, attitude, knowledge and the time available, and these differences need to be managed by the teacher, just as they are managed by the experts in authentic communities.

In communities of practice, models of expert practice are available (Lave & Wenger, 1991). Brown et al. (1989) describe a cognitive apprenticeship approach where the novice learns at the elbow of experts. Experts are present to coach and model the activity. Teacher modelling and use of successful examples of student work and

practice are relevant examples of the functioning of a community of practice in a classroom situation. Schoenfeld (1998) describes how the teacher thinks aloud as they work through a problem and reflects with the students on the strategies used and directions taken. Barab and Duffy (2000) suggest that for practice fields, where novices are learning the practice of experts, teachers coach and model problem solving by asking questions that students should be asking themselves.

Participation in authentic activities, joint enterprise, staged tasks and provision of examples of expert practice as described above have been included in the framework for identification of sociocultural approaches developed for this study.

2.5.4.2 Learning as enculturation

The cultural nature of communities of practice means that learning about a particular discipline can be regarded as a process of enculturation: “individual participation in socially organised practices, through which specialised local knowledge, rituals, practices and vocabulary are developed” (Hennessy, 1993, p. 2). Participating in the actual practice of the community means learning is integral with the situation in which it occurs; it is situated in the community and the activities in which the novices are engaged are the authentic practices of the community. While school learning situations are only practice fields as described in the last section, there can be opportunities for enculturation into the practices, rituals or values, and vocabulary of the relevant community of practice. Science has a specific vocabulary. Everyday words sometimes hold more specific meanings in science; there are words specific to science, and systems of symbols have developed that hold joint meaning across the scientific community. Assisting students to interpret and use specific science vocabulary is an example of enculturation. It is inherent in the aim of the Communicating in Science sub-strand of the Nature of Science strand of the New Zealand Curriculum: students should “develop knowledge of the vocabulary, numeric and symbol systems, and conventions of science and use this knowledge to communicate about their own and others’ ideas” (<http://nzcurriculum.tki.org.nz/Curriculum-documents/The-New-Zealand-Curriculum>).

Osborne et al. (2001) make a case for the use of scientific discourse in the form of argument that draws on evidence as a way of learning both scientific content and culture. Success in primary classrooms in developing such discourse using concept cartoons and puppets has been reported (Keogh et al., 2003). An example of enculturation into the use of scientific processes could be in the use of models. Use of models and analogies as thinking and theoretical tools is common amongst scientists. Coll et al. (2005) argue that use of models can provide opportunities to

learn about the nature of science as well as develop concepts by allowing students to experience building original models and using them to develop theories and explanations, the way models are used by scientists. This view is supported by Henze, van Driel and Verloop (2008) and Hogan (1999).

The examples above have involved enculturation *into* the culture of science. Teachers can assist border crossing *between* cultures by drawing on aspects of students' existing culture to facilitate entry into the new culture (Aikenhead, 1996). Lee and Fradd (1998) describe a teacher who used their Hispanic students' bilingual ability as an analogy to help them understand that there are two scales used to measure temperature, Fahrenheit and Celsius. They discuss the importance of establishing instructional congruence between the nature of science and the language and cultural experiences of the students as a way of enculturation.

Opportunities to develop and practise scientific vocabulary, to recognise and practise use of scientific discourse, verbal or written, and to recognise, practise and discuss scientific processes and values, together with establishment of instructional congruence with students' language and cultural experiences, have been incorporated into the framework for analysis to allow identification of sociocultural approaches to science teaching.

2.5.4.3 Guided participation

Rogoff (2003) describes processes of guided participation common across many cultures. She points out that guided participation is not limited to learning socially desirable skills and practices; they are rather social processes through which learning occurs. These processes could occur in classrooms so for the purpose of this study have been described in terms of the classroom context. Rogoff outlines two common processes: mutual bridging of meanings and mutual structuring of participation.

Mutual bridging of meanings occurs as community members seek a common perspective or language with which to communicate ideas in order to coordinate their actions (Rogoff, 2003). Nuthall (1997) describes this process as appropriation: "the process by which two people come to understand each other and work effectively together. They each appropriate the product of their mutually evolving partnership in the activity. The process is inherently mutual, creative and situation specific" (p. 705). The process involves mutual active interpretation and participation. An example from classroom practice could be a discussion that clarifies the participants' thinking about an idea or process and each adopts

terminology from the other in order to better discuss and understand the idea. This process fits well with Wenger's (1998) perception of learning as negotiation of meaning.

Mutual structuring of participation involves structuring children's opportunities to observe and participate in community practices: deciding what they are present and not present for. Community practices and children's own choices mutually determine the situations from which children have opportunities to learn (Rogoff, 2003). In classrooms students are present for a range of activities; the students themselves determine the level of their participation, although a teacher's role can be seen in part as encouraging student participation. Structure within direct interactions is one of the mutual processes involved here: the deliberate staging or steps where the level and nature of prompts and assistance provided are adjusted and reduced as students participate in an activity with growing competence. This could be seen as similar to the apprenticeship model described above, where novices are first given the basic parts of an activity to do before progressing on to undertake more complex activities. In the classroom it can be seen in progressive withdrawal of support from teachers as students become more competent, a term often referred to as scaffolding (Mortimer & Scott, 2003; Oh, 2005). Rogoff (2003) also suggests that structuring often takes place within cultural practices and tools that are already structured by the culture, for example, in retelling stories and practising roles. The use of narrative or storytelling and practice of routines and taking on roles are further examples of sociocultural practices that may be used in classrooms. Telling the stories of science is advocated by Barker (2001, 2002). Irwin (2000) suggests narrative as a means of promoting understanding of the nature of scientific endeavour. Bell (2005b) describes how teachers and students share narrative in the form of anecdotes as a way of linking prior learning to the science being learnt. Teachers frequently encourage students to take on and practise roles in cooperative learning tasks in primary classrooms. This may also be the case in science learning where students take on and practise a role as time keeper, measurer, observer, or recorder.

Guided participation and its forms as described above have been included in the framework for analysis used in this study to identify sociocultural approaches.

2.5.5 Distributed Cognition

Understanding the nature of communities of practice also assists in understanding the distributed nature of cognition; not all science knowledge resides with one

scientist, for example. Socially mediated action, as described in Section 2.5.2, means learning is jointly constructed and owned, that is, distributed over the participating group. The physical and social resources that surround the person contribute to learning, as a vehicle of thought (Bell, 2005a). The idea is not that cognition is divided up, but rather stretched over the surround, individuals and the available tools (Eames, 2003).

Scott (1997) identified that there are many opportunities to learn science in New Zealand intermediate primary classrooms that extend beyond formal science lessons. These include science focused *New Zealand School Journal* articles read during instructional reading lessons and science focused books accessible in the school library. These examples are a form of socially mediated learning by cultural scaffolding as outlined by Salomon and Perkins (1998) and illustrate ways knowledge is distributed or stretched over the surround as described above. Technological tools, such as computers and calculators, and symbolic tools, such as statistical representations, symbols and language, in the form of books, displays of student work or professionally developed posters, can all help students think (Bell, 2005a). The availability or lack of such tools could afford or constrain learning. Eames (2003) described the distribution of cognition over different people in the workplace as a resource for students in work placements. Similarly the distribution of cognition over members of the classroom community can be seen as a resource; class discussions, conversations with peers and group work stretch the cognition over class members through socially mediated action (Eames, 2003; Salomon & Perkins, 1998).

Distributed cognition in the form of availability of technological tools, symbolic tools and other students as resources and thinking tools have all been included in the framework for analysis and identification of sociocultural approaches developed for this study.

2.5.6 The framework for analysis and identification of sociocultural teaching approaches for this study

Because few examples of comprehensive sociocultural classroom practice with regard to science teaching existed in the literature (Anderson, 2007), Section 2.5 has examined the literature concerning sociocultural theory in order to develop a framework for analysis used in this study to identify sociocultural teaching approaches. This follows the practice of Eames (2003) in studying co-operative student work placements. The framework as developed above is presented in Chapter 3 in describing the methods used for analysis (Table 3.4, p. 67).

2.6 Summary

This chapter has presented a summary of the literature pertaining to this study. The literature regarding teacher knowledge was used to identify an appropriate framework for teacher knowledge. Literature regarding each domain in the selected framework was then presented to provide the detail within each category needed to support analysis of teacher knowledge. The literature describing the development of teacher knowledge for science teaching indicated that while some primary teachers found ways to access appropriate substantive content knowledge, the development of syntactic knowledge for science teaching was more complex, requiring explicit support and positive attitudinal attributes if such knowledge was to be reflected in teaching. The literature concerning development of science PCK revealed ongoing debates as to whether PCK is integrative or transformative, or both. Its development appears to require subject matter knowledge, time, classroom experience, reflection and interaction with other knowledge domains and attitudinal aspects such as confidence. Strong general pedagogical knowledge appears to be a pre-requisite for science PCK development in primary teachers. Finally in this section the literature concerning sociocultural theories and their application to science education was used to develop a framework to support analysis of sociocultural teaching approaches in this study.

CHAPTER 3

Methodology

3.1 Introduction

This chapter discusses the research design and describes the methods for the study. First, the selection of a qualitative or interpretive paradigm and use of a multiple case study approach and their fit with a sociocultural perspective are discussed. The selection and nature of participants, the methods and instruments used for data collection, and the management of ethical issues regarding research in classrooms are described. The analysis of data and application of the frameworks developed from the literature are then described and issues of validity and reliability discussed.

3.2 The qualitative paradigm and multiple case study approach

Cohen, Manion, and Morrison (2011) describe two major research paradigms common in educational research. The first is normative, which links with a positivist view that human behaviour is essentially rule governed and should be investigated using the methods of natural science. Quantitative research includes experimental methods, using traditional scientific approaches involving interventions and controls, or may survey large samples (Cohen et al., 2011). Quantitative surveys have identified that New Zealand primary teachers perceive they have a problem with content knowledge in science (Lewthwaite, 2000; McGee et al., 2003). These studies shed little light on the way this perceived problem impacts in the day-to-day teaching of science in primary classrooms. Scott and Usher (2011) suggest that positivist approaches imply a philosophical stance that assumes that features of human environments have an objective reality existing independently of those who have created them or are observing them. Such a stance is not the view of this researcher and is not commensurate with theories of learning underpinning this study.

The second major paradigm is interpretive or qualitative, where knowledge is considered subjective and to be socially embedded (Cohen et al., 2011). Interpretive research aims to communicate to its audience the understandings developed by the researcher through observing and recording the everyday life of the participants (Merriam, 2001; Patton, 2002). Grbich (2007) suggests "Multiple realities are presumed, with different people experiencing these differently" (p. 8). Reasons for selecting a qualitative approach can include the researcher's stance, the nature of the research questions, or practical reasons for the choice of particular methods of

data collection (Cohen et al., 2011; Patton, 2002). The key concern of qualitative researchers is to understand a phenomenon from the participants' perspectives and in the context in which it occurs (Merriam, 2001; Stake, 2006). This description summarises the aim of the researcher for this study, which is to understand, from teachers' perspectives and the context in which it is used, the nature of teacher knowledge that is utilised and developed in implementing science in New Zealand primary classrooms. The nature of the research questions for this study required a contextual understanding of the phenomenon of teacher knowledge.

The socially embedded nature and contextual focus of qualitative research also links strongly with the sociocultural perspective of this study described in Section 1.3. Learning as described in sociocultural theory occurs in a cultural, social and historical setting. Rogoff (2003) provides a graphic illustration of the situated nature of learning: an isolated picture of a child separated from the surroundings in which the photo was taken enables only a limited guess at the nature of the activity in which he is engaged. A full picture that includes the people with whom he is interacting, the activity in which he is engaged and his physical surroundings, including the tools available to him, enables a richer and more accurate interpretation. Qualitative research appears best placed to provide the full picture required by a sociocultural perspective as it "can reveal how all the parts work together to form a whole" (Merriam, 2001, p. 6).

As Traianou (2007) points out, teacher knowledge relies on its functionality: "the ability to employ knowledge as a resource in order to achieve situated, contextualised goals emanating from problem-solving situations in the communities of practice to which they belong" (p. 37). Science in New Zealand primary schools is commonly taught in topic-based units of work (Bull et al., 2010). Each science focused unit would bring its own contextualised goals and problems, so studying a teacher implementing such a unit would provide opportunities to study the phenomenon of teacher knowledge for science, its nature, development and influence, in context. The study of the implementation by a teacher of a unit would also provide a natural boundary in terms of subject material and duration. Merriam (2001) describes case studies as "intensive descriptions of a single unit or bounded system" (p. 19). Stake (2006) describes cases as "entities" (p. 2). For these reasons a case study approach was adopted as most suitable for this study. The cases were bounded by time (the duration of the science unit), place (the environments, normally the school and classroom, in which the teaching occurred), and the participants, the teacher and their class. The cases were also bounded by the learning area; only science lessons were observed.

Cohen et al. (2011) suggest many ways to categorise case studies. The purpose of this study was to examine the issue of teacher knowledge for science, its nature, development and influence. Theories about the nature of teacher knowledge and its development exist and have been examined in Chapter 2. Merriam (2001) describes interpretive case studies as using descriptive data to “illustrate, support, or challenge theoretical assumptions held prior to data gathering” (p. 38). This purpose best fits that of this study. Yin (2003) suggests multiple case studies to avoid the criticism of uniqueness. Merriam (2001) proposes that a variety of cases in a study allow more compelling interpretation. Miles and Huberman (1994) state that similarity and difference between cases helps understanding and strengthens findings. Stake (2006) describes multiple case study as suitable for investigating how a phenomenon operates in different situations: each case adds to the understanding of the phenomenon. He adds that while science has an expectation that case selection is carried out statistically and will therefore represent a population of cases, professional services, including teaching, have a different purpose in studying cases. Such professions find the detailed description of interrelationships between functions and contexts enabled by multiple case study more useful. A multiple case study approach was therefore chosen to strengthen and enrich this study.

3.3 Case identification and selection and nature of participants

The nature of teacher knowledges used in science teaching and their development were the focus of key questions governing the design of this study. For this reason it was decided that there was most to be learned from observing cases where teachers were accustomed to teaching science and regarded as teaching it well. Purposive sampling involves selection of cases from which most can be learned (Merriam, 2001). A purposive sample was sought of schools where science teaching was known to occur regularly in a well-regarded way by those experienced in primary science. Studying cases from such a sample would enable comparisons and identification of commonalities and differences that would contribute to understanding how primary teachers use their knowledge to teach science and develop the knowledge they need. Including a number of cases from the same purposive sample would also help allay criticisms of uniqueness (Yin, 2003). A restriction placed on case selection was that data collection needed to fit in with the researcher’s work commitments, so schools had to be accessible in the timeframes available. The purposive sample was therefore limited to a set geographical region.

For this study, Years 7 and 8, the final two years of primary schooling in New Zealand, were selected as the level at which to observe the teaching of science. The senior primary level is likely to be the most demanding in terms of content knowledge, so cases from this level would inform ways in which teachers develop the content knowledge required to teach science. The focus on student perspective required that students were able to verbalise their ideas about learning in science. As Ares and Gorrell (2002) point out from their experiences in researching this age group, students in these years (aged 11-13) are “not apathetic or unreflective. On the contrary they were thoughtful in their responses and had definite opinions about effective teaching and meaningful learning” (p. 264).

In order to locate schools pursuing science at senior primary level, a range of experts in the primary science field in these regions was consulted. These included the primary science advisers, a lecturer in primary science education at another university in the set region, and the team at the Royal Society who administer the the Crest science and technology programme available to primary schools. Each of these was asked to develop a list of schools that they knew were actively involved and well regarded in science at Years 7 and 8. A further list was sought from the Education Review Office (ERO). The quality of science teaching in New Zealand schools at years 4 and 8 was evaluated by ERO during their regular reviews in 2003 (ERO, 2004). In this report a measure of overall quality of teaching in science was determined for each reviewed school based on judgments made for a series of evaluation indicators. Indicators included “evidence of high standards and expectations for learning, capable, knowledgeable teachers, a wide range of teaching strategies, effective planning and classroom management, and the use of appropriate resources” (p. 7). Schools were classed as ‘effective’, ‘adequate’, ‘not always effective’ and ‘rarely effective’. A request was made to ERO for a list of schools classed as ‘effective’ in the required region. These schools were approached by ERO and asked if they were prepared to be contacted for this study. A list of willing schools was then provided by ERO. This list was combined with the lists provided by experts to provide the purposive sample.

New Zealand students may receive their education at Years 7 and 8 in a variety of school types. Full primary schools and intermediate schools comprised the purposive sample. When exploring differences in delivery between full primary and intermediate schools, philosophy and practice appear more important than the actual type of school the student attends (Nolan & Brown, 2001). A study of over 300 full primary and 85 intermediate schools in New Zealand states: “The majority of

intermediate schools take an approach to curriculum organization and delivery that is similar to the style of education provided at full primary schools” (ERO, 2001, Part 1, p. 25). That schools were well regarded for science teaching was considered more important than the type of school and so five prospective study schools were randomly selected from this sample.

Once ethics approval for the study was granted, principals of prospective schools were contacted by telephone, informed briefly about the project and asked if they had staff teaching at Year 7s and 8 who had been at the school for five years or longer who might be interested in participating. The teacher’s length of time at the school was the final criterion for selection: the teacher in each case should be among those accredited with the school’s reputation for teaching science at Years 7 and 8. Four teachers meeting this criterion indicated interest and became participants in the project. Of these, three cases are fully presented and analysed with one left as backup in case a school pulled out. In the event it was not required. Each teacher’s implementation of a unit of science with their class formed a case. Details concerning the teacher, class and school in each of the three cases are provided in Table 3.1. The nature of the science unit implemented and dates of data collection are also included.

Table 3.1: Summary of Cases

	Case 1	Case 2	Case 3
Teacher	T1	T2	T3
Date of data collection	March, 2007	May-June 2007	May-July 2009
Gender	Male	Female	Female
Ethnicity	European	NZ European	NZ European
Age range	50-60	30-35	40-50
Initial teacher education: country	New Zealand	New Zealand	New Zealand
Teaching experience	35 yrs in NZ schools, mostly at Yr 7 & 8 level	9 years in NZ schools, mostly at Yr 7 & 8 level. 4 months supply teaching overseas	Wide experience in education in New Zealand: primary teaching, reading recovery, resource teacher of learning and behaviour. 6 years in United Kingdom working with secondary students excluded from school
Management experience	Deputy Principal; Teaching Principal	Syndicate leader	Syndicate leader

	Case 1	Case 2	Case 3
Science experience	Secondary school science. Teacher in Charge of Science for 30 years. Professional development for implementation of <i>SiNZC</i> (MOE, 1993a)	Secondary school science. Teacher in Charge of Science for 7 years. No formal professional development in science. Mentoring from former teacher in charge of science	Secondary school science. Teacher in charge of science. Participated in science professional development in 2005-6 organised by the school
Class	Class 1	Class 2	Class 3
Class size	8	30	30
Number of Year 7 students	1	0	16
Number of Year 8 students	7	30	14
Number of male students	4	17	16
Number of female students	4	13	14
School	School 1	School 2	School 3
School decile	10	10	8
School ethnic composition as per then current ERO report	New Zealand European 98% Māori 2%	New Zealand European 81% Māori 5% Asian 9% Samoan 2% Other ethnic groups 3%	New Zealand European 58% Māori 11% Asian 17% Pacific 3% Other ethnic groups 11%
School size	47 students	546 students	236 students
School type	Full primary	Intermediate	Full primary
Frequency of science	3-4 week units, taught 3-4 times per year, with 2-3 lessons per week during the unit	5-8 week units, taught 3-4 times per year, with 2-3 lessons per week during the unit	Term long inquiry units, one or two major science focused units per year. 3-5 lessons per week integrated across at least English
Science Topic Observed	Rocky shore	Science Fair	Fitness Inquiry
Date	March, 2007	May-June, 2007	May-July, 2009
Curriculum document applicable	<i>SiNZC</i> (MOE, 1993a)	<i>SiNZC</i> (MOE, 1993a)	<i>The New Zealand Curriculum</i> (MOE, 2007)
Duration (Weeks)	3½ weeks	8 weeks	11 weeks
Number of Lessons taught	7	10 (by T2, further lessons in unit taught by teaching student)	27
Number of science lessons observed	7	6	23
Number of science lessons taught but not observed	0	4	4
Hours spent in lesson observation	7hrs 21 mins	5 hrs 26 mins	21 hrs 17 mins

As can be seen in Table 3.1, while the use of a unit of science as the natural boundary for each case was logical in terms of content and duration (each teacher moved on to teach a different learning area at the end of the unit), it also provided limitations to this study. The variability in the number of lessons in each case is an artefact of this boundary and reflects the variability that exists in the delivery of science education in New Zealand. Studying more than one unit for each teacher would have strengthened the study but was not practical as each teacher did not plan to teach science till the following year. The variation in the number of lessons observed is therefore a limitation of the study.

3.4 Data collection methods

The timeline for data collection was 2007-2009. Data were collected for Case 1 and Case 2 in 2007 and for Case 3 in 2009. The time lag between data collection for the first two cases and the final case was because T3 was not teaching science until mid 2009. The time between data collection was used to strengthen the theory underpinning the frameworks for analysis.

Prior to commencement of the implementation of the science unit forming the case study, the principal of the school and the teacher involved provided signed consent, and consent forms for students were given to the teacher who managed the process of obtaining signed consent from parents and caregivers. The final research question for this study investigates students' perceptions of their learning. As part of this aspect of the study four students, two male and two female, who were prepared to participate in regular interviews during the unit were selected from each case study class. The teacher was asked to identify students who usually showed average achievement with no special interest in, or talent for, science. Students with a propensity toward science may not have represented the common perceptions of students in the class. These students, whose parents or caregivers had given permission for their participation in the project including that they be interviewed regularly, were then approached by the researcher and invited verbally to participate. When this process was complete the researcher was introduced to the rest of the class, the purpose of her presence was explained verbally, and the study of the implementation of the science unit began.

A case study requires in-depth data and uses a range of methods for data collection (Cohen et al., 2011). Often the most useful source of data concerning the activity and functioning of a case is direct observation; contexts can influence activity and so

require study and description (Stake, 2006). Other useful sources are interviews and documents (Merriam, 2001). Each data collection method has advantages and disadvantages. Multiple sources of evidence can provide concurrent validity, if there is high correlation of data from different instruments (Cohen et al., 2011). Observations were supplemented by audio recording of lessons, semi-structured and informal interviews, and questionnaires. Documents such as teacher designed worksheets offered to the researcher by teachers provided an additional source of data. The data collection methods used in this study, their purpose and the research question they informed are listed in Table 3.2. Each of the methods of data collection listed above is then discussed and described in subsequent sections.

Table 3.2: Data collection methods

Data collection method	Purposes	Research questions informed
Classroom observation	To collect data regarding teacher knowledge and beliefs used in science teaching, approaches to science teaching, the nature of interactions and activities, and the degree of student engagement	1, 2 and 3
Audio-recording of observed lessons	To collect data regarding teacher knowledge and beliefs used in science teaching, approaches to science teaching, and the content and nature of interactions	1, 2 and 3
Interviews with teacher	To collect data regarding the teacher's knowledge, beliefs and intentions and approaches to science teaching	1, 2, and 3
Teacher created documents such as planning documentation, written activities and worksheets	Provide data regarding the teacher's knowledge, beliefs, intentions and approaches to science teaching	1, 2, and 3
Interviews with focus students	To collect data concerning the students' perceptions of their learning with regard to science	4
Questionnaires completed by all students in the class	To collect data concerning the students' perceptions of their learning with regard to science	4

It should be noted that the focus for the collection of student data was to address the fourth research question for this study which was to examine the impact on students' perceptions of their learning of the set of knowledges drawn on by the teacher in implementing science in each case. The influence of teacher knowledge on student learning was an omission of many studies of teacher knowledge noted in the literature review. As discussed in Sections 1.2.1 and 1.2.2, a major focus for the design of data collection tools, as well as analysis, was the relative regard and value demonstrated by students concerning syntactic as opposed to substantive learning opportunities and outcomes.

3.4.1 Lesson observation

Observation of the complex social setting of the classroom is most reliable when conducted over a period of time or on more than one occasion (Wilson, 2009). Capturing the breadth of knowledge drawn upon during implementation of the science unit required that as much of the science unit was observed as possible. The total number of science lessons taught by the teacher during the unit and the number observed for each case were included in Table 3.1. A format for recording observation of each lesson, adapted from Moeed (2010), is included in Appendix A. The number of students present, their general demeanour, and the size and nature of groups employed during activities were noted. Activities and teacher actions were described; times at which activities began and ended were noted. The degree of engagement in activities of each focus student, as measured by approximate proportion of time spent on task during the activity, and of the class as a whole, as measured by approximate proportion of students on task, was identified to contribute to description concerning participation. Engagement has been interpreted differently in different situations. Behavioural engagement was recorded in these observations: whether a student was involved and participating (Fredericks, Blumenfeld, & Paris, 2004). In addition to completing forms as activities proceeded during the lesson, field notes recording the layout of the classroom and any drawings or notes made by the teacher on the board were kept. Notes of any incidental conversations with focus students or the teacher and the researcher's reflections were also made immediately following observed lessons. Recording observations enabled teacher knowledge to be identified in action. Reflection following each observation allowed the researcher's interpretations or queries to be addressed in the next observation or interview. As Merriam (2001) suggests, data collection and analysis are interactive and simultaneous in qualitative research, allowing for more trustworthy findings.

Despite the structure implied above, observation in this study fits best with descriptions of participant observation. Cohen et al. (2011) suggest non-participant observers stand "aloof from the group activities they are investigating and eschew membership" (p. 297). In the natural setting of the classroom it is hard not to be a participant. The researcher was present for nearly all science lessons and became an accustomed presence, chatting informally before or after lessons and helping tidy up at the end of the day. Although primarily sitting at the back of the class observing during lessons, she was treated by participants as a participant: she was asked questions by students and sometimes included in their activities and conversations. Teachers sometimes involved her in proceedings, asking her to collect items from the

fridge prior to an activity for example, or sharing an amused glance over an occurrence. Merriam (2001) emphasises the need for a qualitative case study researcher to be a good communicator who empathises with participants. The occurrences described above helped build rapport and were indicative of its development. Because the observations took place over a number of weeks the researcher was able to establish “informal relationships” with participants that enabled her to “discern ongoing behaviour as it occurred” and note its “salient features,” the products of participant observation useful for interpretative inquiry (Cohen et al., 2011, p. 298). However, the researcher’s role was known to the group and at no time was there any deliberate direct influence on the nature or direction of events. Any participation was minimal and always secondary to the role of information gatherer (Merriam, 2001). The researcher’s role as science teacher educator was known to each of the teacher participants and may have influenced their practice, making this a limitation of the study.

The challenges of observation include that observers bring their own biases and experiences, and may also interrupt the environment so that observed lessons do not represent the norm (Wilson, 2009). In this study, the researcher brought to her observations her experience of six years as a visiting lecturer observing and feeding back on the practice of pre-service teachers, as well as her experience as a primary teacher and former scientist. While her classroom observation skills were well developed, her awareness and expectation of experienced teacher practice may have been reduced. Her expectations for science teaching may have been high. Her experience as a lecturer in primary science education may have biased observations and influenced the teacher’s practice. Sustained observation during the science unit ameliorated changes in response to the presence of the researcher, but teachers may have endeavoured to exhibit their best rather than normal practice with regard to science teaching. Such practice would still elucidate facets investigated by the first two research questions, but may have influenced findings regarding the degree of sociocultural approaches, if this reflected teacher beliefs concerning best practice.

Audio-recordings were made of each observed lesson using a small digital recorder and high quality stereo microphone to provide a more complete record of classroom discourse than would have been possible using observation alone (Wilson, 2009). Transcribed recordings provided declarations of teacher knowledge as well as examples of it in action, including the nature of classroom discourse. Student interactions during activities did not record well, but were not the focus of this study.

Teachers frequently gave the researcher documents relevant to their science teaching. Documents included copies of long-term plans, worksheets, assessment tasks and written criteria for student tasks. These were dated and added to field notes, providing further data for analysis. Such material also helped clarify the focus of unobserved lessons in conjunction with discussions with the teacher.

3.4.2 Interviews

Interviews can access beliefs, feelings and motives and elicit reasons and explanations (Silverman, 2006). Cohen et al. (2011) describe semi-structured interviews as a prepared schedule that is “sufficiently open ended to enable the contents to be reordered, digressions and expansions made, new avenues included and further probing undertaken” (p. 236). This form of interview was used in this study as it allowed flexibility to explore issues that arose pertinent to the research questions, while the schedule that was developed ensured coverage of the aspects under investigation. An initial interview with the teacher and each focus student was audio-recorded prior to or near the beginning of the observed unit. If possible an informal interview with the teacher probed their intentions for learning prior to a lesson. Interviews with focus students and the teacher were recorded whenever possible following a science lesson. Teachers often volunteered their thoughts on student responses or progress and included reflections about what happened, overall progress and next steps in implementing the unit. These interviews did not occur each lesson because of the busy nature of classrooms and teachers but were recorded at least once each week during the unit. Final interviews with the teacher and focus students were recorded on completion of the unit. The schedules developed for teacher interviews are included in Appendix B. Schedules for focus student interviews are provided in Appendix C. All recorded interviews were transcribed.

Interviews did not ask the teacher directly about knowledge as this may have appeared like a test and created unease resulting in abnormal practice. Traianou (2006) describes the inadequacies of direct tests of teacher knowledge. Questions were designed to provide opportunities for teachers to share beliefs and knowledge using familiar terms and practices.

There is a likelihood that an interviewee will give an answer they think the researcher wants to hear (Wilson, 2009). The long-term involvement and the number of interviews in this study mitigated against this problem to some extent as did the use of whole class questionnaires, described in the next section.

3.4.3 Class questionnaires

Questionnaires are useful for collecting information from large numbers of participants. Many questions can be asked about a particular aspect and they offer anonymity to participants not available in interviews (Wilson, 2009). However, they have limited scope and flexibility and participants may not record or recall information accurately (Cohen et al., 2011; Wilson, 2009). Most students in the class completed a questionnaire administered within a week of the end of the unit. The questionnaire was qualitative in nature and designed to obtain a broader range of perceptions concerning learning than that provided by interviews with focus students, although the latter provided greater flexibility to follow issues of interest, check interpretations and add detail. The order of questions was important so that students' perceptions concerning new learning were obtained prior to asking about the specific topics that were the intended learning as identified by the researcher. Early open questions invited students to identify new or important learning, learning supports and enjoyment. Later questions provided lists of activities for which students were asked to use Likert scales to indicate their perceptions of enjoyment and utility for learning. Likert scales also sought students' perceptions concerning utility for learning of teacher actions and of existing and new learning regarding the concepts and science processes that were the focus of the unit, again identified by the researcher. Finally, open questions explored students' overall perceptions of the utility of the unit. The questionnaire used in Case 3 is provided in Appendix D as an example.

The questionnaire was administered over several sessions, for reasons described in Section 3.4.4. The researcher was able to complete this in Case 1, but to obtain responses within a week of completing the unit, the questionnaire was administered by a student teacher in Case 2, and the teacher in Case 3, where a teacher aide helped two students new to the English language record their responses. In each case questionnaires were numbered for anonymity and questions were read aloud.

3.4.4 Piloting of data collection tools

A pilot study of a comparable case was completed during which all the above instruments were tested in order to check their effectiveness for collecting the data needed to answer the research questions. The questions used in interviews and the questionnaire were discussed with the teacher and a group of pilot students. Some questions were consequently rephrased and the final general questions added to the questionnaire. The questions about general teaching and learning were added to the interview. The length of the questionnaire was problematic but all questions

were useful. It was therefore decided to administer it in sections at different times to maintain students' attention.

3.5 Ethical issues

Approval for this study was given by the Victoria University of Wellington Human Ethics Committee. Ethical research in education requires consideration of the wishes of those external to the research, consequential effects for the participants, duties and motives, and the needs of issues of trust between the individuals involved (Wilson, 2009). Cohen et al. (2011) describe informed consent as the participant's right to weigh up the risks and benefits of being involved in a study. Information sheets were provided for the principal, teacher and parents or caregivers of students in the class. Written consent was sought from the principal of the school and from parents of students in the class as well as the teacher. Sample information sheet and consent forms are provided in Appendix E.

Information sheets and consent forms for students were given to the teacher to send home to parents with students. The majority of, but not all, forms were returned. No parents declined permission. Observations were not recorded for students for whom consent was not received and they did not participate in interviews. All student questionnaires were anonymous. Students were instructed that they could leave questions and questionnaires blank if they did not wish to participate.

The researcher approached prospective focus students whose parents had consented to their participation, explained the nature and purpose of the research verbally, invited questions, and assured students that declining to be involved was acceptable, although none did. Students were assured that nothing they said would be revealed to their teacher or others in their school. The researcher took care that such confidentiality was maintained. Merriam (2001) describes potential for embarrassment and invasion of privacy through observation and interview as participants may reveal aspects that they did not intend. Participants were asked if they were happy to have interviews recorded and reminded they could ask for the recorder to be turned off at any time and the recording deleted. Teachers were sent transcripts of their interviews for checking. Pseudonyms were used in reporting on the study to protect identities of participants and their schools.

3.6 Analysis

Data analysis involves “organising, accounting for and explaining the data” identifying “patterns, themes, categories and regularities” (Cohen et al., 2011, p. 237). In multiple case analysis a phenomenon is first explored within each case and then across cases (Stake, 2006).

The first and third research questions were analysed using an abductive reasoning process: a move from lay to technical accounts (Scott & Usher, 2011). The literature, as reviewed in Chapter 2, provided categories for coding data to facilitate the answering of the first and third research questions. Coding is the “ascription of a category label to a piece of data” (Cohen et al., 2011, p. 428). Merriam (2001) warns that use of external categories should be compatible with the purpose and theoretical framework of the study or there is a risk of the major effort becoming data selection rather than theory generation. In each case, lesson summaries were developed showing the order and nature of learning experiences and teacher actions, the content covered, duration, and class engagement. A typical example is provided for each case (Appendices F, J and N). A lesson log showing the sequence of activities and content for the unit was developed (Appendices G, K and O). Total time spent on each type of activity was represented as a graph (Figures 4.1, 5.1 & 6.1).

A major data source was the detailed lesson transcripts. These were formed from transcriptions of audio recordings of each lesson by interpolating observation data describing teacher actions and learning experiences, and teaching documents at the points at which they occurred in the lesson. All detailed lesson and teacher interview transcripts were coded according to the knowledge framework, and again for the sociocultural framework. All the excerpts that had been coded for a particular category were then put together, compared, and summarised to give as complete a picture of the nature and range of each category as possible for each case study. This process provided opportunities to check and compare coding across transcripts as well as compare and triangulate interview and observation data.

Scott and Usher (2011) describe the dilemma as to “how far theorists and empirical researchers should go... whether it is methodologically acceptable to import other notions” which participants may not recognise (p. 57). Understanding the nature of knowledge that primary teachers use in teaching science and interpreting it in terms useful to other researchers was a purpose of the first research question. While each teacher’s knowledge was categorised according to the literature, the description of *its nature* formed the findings, preserving a strong relationship between findings and

the original data. Merriam (2001) suggests categories should be sensitising: sensitive to the data and able to be recognised by an outsider. The categories of teacher knowledge as defined from the review of the literature (Section 2.3) and used in analysis of the data as described above are provided in Table 3.3.

Table 3.3: Framework for the analysis of teacher knowledge with respect to science⁽¹⁾

<p>1. General pedagogical knowledge and beliefs:</p> <p>a) General instructional strategies and teaching approaches (Morine-Dershimer & Kent, 1999):</p> <ul style="list-style-type: none"> • behaviourist: mastery and extrinsic rewards • developmental: stepwise progression, readiness • constructivist approaches: identification and restructuring of existing student ideas, teaching for cognitive conflict or conceptual change • sociocultural approaches: see separate framework (Table 3.4) <p>b) Classroom management & organisation (Morine-Dershimer & Kent, 1999):</p> <ul style="list-style-type: none"> • time students spend on appropriate academic tasks • structure of new information • links made to prior knowledge • monitoring of student performance • provision of feedback • management of multiple tasks; awareness • identifying and resolving problems effectively and quickly • setting and maintaining clear expectations for behaviour, work standards and classroom procedures • systems of consequences (Morine-Dershimer & Kent, 1999) • <i>management and organisation of groups</i> (arose from analysis) <p>c) Classroom communication and discourse (Morine-Dershimer & Kent, 1999):</p> <ul style="list-style-type: none"> • interactive/authoritative communicative approach • interactive/dialogic communicative approach • non-interactive/dialogic communicative approach • non-interactive/authoritative communicative approach <p>(Mortimer & Scott, 2003)</p>	<p>2. Knowledge of and beliefs about general aims purposes and values of education and assessment</p> <p>3. Knowledge of and beliefs about learning and learners:</p> <p>a) Learning and human development as it informs practice (Shulman, 1987)</p> <p>b) Student characteristics – generalised for a particular age or year group (Turner-Bisset, 1999)</p> <p>4. Knowledge of and beliefs about the educational context:</p> <p>a) New Zealand school system and structures including governance and financing of schools</p> <p>b) Character of the New Zealand community including its social, political, cultural (including bicultural emphasis) and physical environments (Cochran et al., 1993)</p> <p>c) Workings and character of the school including its social, political, cultural (including bicultural emphasis) and physical environments (Cochran et al., 1993)</p> <p>d) Knowledge of particular students including their social, political, cultural (including bicultural) backgrounds and attitudes together with knowledge of their abilities, learning strategies, developmental levels, attitudes, motivations and experiences (Cochran et al., 1993; Turner-Bisset, 1999)</p>
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5. Science content knowledge and beliefs:

- a) Syntactic knowledge of science (Schwab, 1964; Shulman, 1986, 1987):
 - Knowledge and beliefs about the nature of scientific knowledge: processes of knowledge generation, validation, and dissemination, and the history and philosophy of science (Hodson, 2009)
- b) Substantive knowledge of science (Schwab, 1964; Shulman, 1986, 1987):
 - Knowledge of general concepts, principles, relations, topics (Hashweh, 2005)
 - Knowledge of higher order principles or conceptual schemes (Hashweh, 2005)
 - Knowledge of approaches, or of different ways of relating topics to other discipline entities (e.g., molecular approach to biology) (Hashweh, 2005)
 - Non-target content knowledge (Cochran et al., 1993)
 - Topic specific content knowledge (Cochran et al., 1993)

Note: the above aspects of content knowledge may be of two forms (Tiplady, 2004)

- Background content knowledge (from secondary and tertiary education, life experiences and professional development)
- Content knowledge developed as required

6. Curriculum knowledge and beliefs:

- a) New Zealand wider curriculum documents (Ministry of Education, 1993b, 2006, 2007)
- b) Specific curriculum documentation pertaining to science found in *Science in the New Zealand Curriculum* (MOE, 1993a), *New Zealand Draft Curriculum* (MOE, 2006) and *New Zealand Curriculum* (MOE, 2007) including science aims and achievement objectives
- c) Vertical (higher and lower levels within science) (Grossman, 1990)
- d) Horizontal (curricula of different subjects at same level including PCK from other subjects) (Appleton, 2006; Grossman, 1990)
- e) Resources
 - Teaching Materials (Shulman, 1987)
 - Equipment (scientific and everyday) (Appleton, 2006; Hashweh, 2005)

7. Science pedagogical content knowledge and beliefs

- a) Orientation toward teaching the subject: process, academic rigour, didactic, conceptual change, activity-driven, discovery, project-based, inquiry, guided inquiry (Magnusson et al., 1999)
- b) Knowledge of science instructional strategies
 - Demonstrations (Treagust, 2007)
 - Explanations (Treagust, 2007)
 - Representations, analogies and models (Treagust, 2007)
 - Use of scientific discourse types (Treagust, 2007)
 - Activities that work (Appleton, 2003)
 - Syntactic strategies (Smith, 1999)
- c) Knowledge of science assessment
 - Dimensions of science learning to assess (Magnusson et al., 1999)
 - Methods of assessing science learning (Magnusson et al., 1999)
- d) Student preconceptions and difficulties
 - Commonly acknowledged student pre-conceptions and difficulties (Shulman, 1987)
 - Prior conceptions of the topic held by group of students being taught (Cochran et al., 1993)

⁽¹⁾ This framework was developed from the literature as discussed in Sections 2.2 and 2.3. The main headings are those suggested by Shulman (1986, 1987). The sub-headings for science PCK are those suggested by Magnusson et al. (1999) and used by Abell (2007). Other aspects are attributed to authors as shown in the table.

Instances of these categories were identified from repeated readings of each detailed lesson and teacher interview transcript. In the first reading any categories that were immediately apparent were identified. The audio recording of the transcript was used simultaneously to check and add nuance to interpretation. In subsequent readings the transcript was carefully re-checked for each category, one at a time. Instances were compared to see how they fitted with others by putting all instances together (Merriam, 2001). Transcripts analysed early in a case were rechecked for consistency after all were completed. Transcripts from previous cases were also rechecked. One further category within the general pedagogical knowledge domain arose during analysis: group management and organisation was identified as a subcategory of classroom management and organisation.

Instances of subcategories of the classroom management and organisation category were counted and their frequencies presented as a graph. Instances from each category were used to develop a description of the nature of the knowledge for each domain for each case.

The identification of sociocultural teaching approaches, part of the general pedagogical knowledge domain and investigating the third research question, was facilitated by the development of another framework of categories as discussed in Section 2.5 and listed in Table 3.4.

Table 3.4: Framework for identification of sociocultural teaching practices⁽²⁾

<p>Socially mediated action (Salomon & Perkins, 1998)</p> <ul style="list-style-type: none"> • Active social mediation of individual learning. • Social mediation as participatory knowledge construction. • Social mediation by cultural scaffolding. • The social entity as a learning system. • Learning to be a social learner. • Learning social content. <p>Situated and participatory activity (Lave & Wenger, 1991; Rogoff, 2003)</p> <ol style="list-style-type: none"> 1. Participation in communities of practice.(Lave & Wenger, 1991; Wenger, 1998) <ul style="list-style-type: none"> • Authentic activities (Barab & Duffy, 2000; Grabinger et al., 2007) • Joint enterprise • Staged tasks • Examples of expert practice 2. Enculturation (Aikenhead, 1996; Hennessey, 1993) <ul style="list-style-type: none"> • Opportunities to develop and practise subject/topic specific vocabulary • Opportunities to recognise and practise subject specific dialogue and text • Opportunities to recognise and discuss subject specific values and processes • Establishing instructional congruence with students' existing language and cultural experiences (Lee & Fradd, 1998)

3. Guided participation (Rogoff, 2003)
 1. Mutual bridging of meanings
 2. Mutual structuring of participation
 - Structuring of direct interactions
 - Structuring using narrative
 - Structuring using routines
 - Structuring using role plays

Distributed Cognition (Bell, 2005; Eames, 2003; Salomon & Perkins, 1998)

- Availability of technological tools
- Availability of symbolic tools relevant to the subject/topic
- Availability of other students as a resource and thinking tool
- *Availability of natural objects* (arose from analysis)

⁽²⁾ This framework was developed as described in Section 2.5 in a process similar to that used by Eames (2003).

These categories were used in identifying instances of sociocultural practice. A further category of distributed cognition, availability of natural objects, arose during analysis. Such identification of new categories mitigates against concerns expressed by Merriam (2001) that use of external categorisations may result in finding only what the researcher is looking for. Schematic accounts of each lesson were developed showing each teacher's sociocultural practice using a format based on that of Thorpe (2007). This format enabled the researcher to see durations as well as frequencies of use of particular practices and identify any patterns in their use or associations with particular learning experiences. A typical lesson analysis for each case is presented in Appendices H, L and P. The full graphs and instances assigned to each category informed descriptions of sociocultural practices presented in each case.

Analysis of data relating to the research question concerning development of knowledge for teaching was carried out concurrently with the analysis described above. Relevant statements or instances concerning the development of science content knowledge and PCK were identified, compared and grouped according to common attributes within each case. Processes of knowledge development exhibited by the teacher in each case were identified and described. During cross-case analysis these were compared and similarities and differences between cases identified.

Data from student interviews were summarised into tables and common themes identified. Responses to open questions from the whole class questionnaire were coded and common themes identified inductively. Responses to Likert style questions were graphed and common patterns identified. A major focus for analysis of students' responses was their perception of the comparative importance of the

nature of their learning which was categorised as syntactic or substantive according to the definitions used for teachers' science content knowledge as described in Table 3.3. As described in Section 1.2, these categorisations of learning outcomes were important considerations both for the researcher and also with regard to outcomes described in the New Zealand curriculum documents guiding science teaching during the study.

Each case was organised and presented by research question, then all three cases were examined together by research question. The analysis of each case was carefully compared with the others for each category of teacher knowledge, each category of sociocultural practice, methods of knowledge development and characteristics of students' perceptions of their learning. Comparisons, commonalities and differences were identified, testing tentative relationships by looking for negative evidence, i.e., checking cases for examples where a proposed relationship did not occur (Wilson, 2009), to develop the findings for this study which are presented in Chapter 7.

Merriam (2001) discusses the need for a process of constant comparison in analysing qualitative data, which best describes the nature and practice of analysis in this study. In analyses of individual cases using the frameworks and in examining the data across cases there was a constant comparison of examples allocated to a category, within and between transcripts and within and across cases, providing opportunities for triangulation from different sources, ensuring that codings were applied in the same way and that the range of practices, knowledge and beliefs assigned to a category, together with any discrepancies, were described adequately in reporting the findings.

Lesson transcripts, teacher and student interviews were labelled according to form and date. Excerpts from these have been identified in this study by placing the speaker's pseudonym in front of the transcript label. T1/LT/14/3 implies T1 is the speaker in an excerpt from a lesson transcript dated 14th March. T3/I/17/5 indicates T3 is the speaker in an excerpt from an interview transcript recorded on the 17th May. FN denotes field notes. Student speakers were denoted by S1, S2 and so on in speaking order within an excerpt. Focus student pseudonyms were formed using the case study and focus student number: C1FS2 is the second focus student from Case Study 1.

3.7 Reliability and validity

Reliability in qualitative research concerns whether results are consistent with the data collected (Merriam, 2001). Internal validity seeks to show that findings can be sustained by the data (Cohen et al., 2011). It requires evidence of a connection between the conclusions made and the procedures used in collecting and interpreting data (Wilson, 2009). The theory underpinning the study, described in Chapters 1 and 2, the researcher's stance, described in Section 1.2.1, the context in which the study occurred, described nationally in Section 1.2.2 and for each case in Sections 4.1, 5.1 and 6.1, together with the rationale and decisions regarding case and participant selection and data collection instruments and methods of analysis are all described to indicate the degree of reliability that can be placed on this study. The use of multiple data sources, or triangulation, for each question, as shown in Table 3.2, strengthens its reliability (Merriam, 2001). Triangulation was a reason for using three schools with similar external judgements concerning their socioeconomic status and the regard in which they were held with respect to science.

A possible threat to internal validity was that non-representative findings could arise from limited data sources. Triangulation through use of multiple cases and data sources provided a range of perspectives on each research question. Another concern was misinterpretation by the researcher. Observing many lessons within cases allowed repeated observations of phenomena. Multiple interviews allowed initial interpretations by the researcher to be checked and the views and actions of the teacher or student to be better represented. Transcripts of interviews were sent back to teachers for checking, although students did not have this opportunity. Constant comparison and rereading of the data during analysis and examination for negative evidence during formulation of the study findings also mitigated against misinterpretation. The description of the researcher's perspective in Section 1.2 allows the reader to see the position from which the researcher approached the study and to identify possible bias in interpretation relating to their perspective. The use of frameworks containing a set of categories developed from a wide range of literature to support analysis mitigates against researcher bias. Provision of detailed descriptions and excerpts for each category in each case also links the data strongly with the analysis, thus enabling the reader to identify the researcher's interpretation for each category.

External validity involves generalisability which is problematic in situated qualitative research and therefore is interpreted as comparability and transferability (Cohen et

al., 2011). As Merriam (2001) suggests, the “general resides in the particular” (p. 210). Detailed descriptions of settings have been included in findings that will enable others to decide their fit with other situations. Similarly, the provision of details regarding the national setting of the study and the researcher’s perspective supports others to decide on the applicability of the study to their situation.

This chapter has identified and discussed the methods used for data collection and analysis. Case studies are presented in Chapters 4, 5 and 6, organised by research question, except that sociocultural approaches, the focus of the third research question, are described within general pedagogical knowledge as in Table 3.3. Chapter 7 presents the findings of cross case analysis by research question and Chapter 8 summarises and discusses findings.

CHAPTER 4

Case Study 1

4.1 Setting

Case Study 1 involved an experienced teaching principal, T1, in a rural school teaching a unit on the rocky shore to eight Year 7 and 8 students. The rocky shore topic was taught across the whole school at the same time. A whole school rocky shore trip was organised for the second week of the unit.

4.1.1 School 1

School 1 was situated inland, about twenty kilometres from the nearest small town in a quiet rural location. There were two classes, Years 1-3 and 4-8. The principal and a part-time teacher shared the Year 4-8 class. For this unit the senior class was split into a Year 4-6 class, taken by the part time teacher, and a Year 7-8 class taught by the principal. The latter formed the case study.

Most students came from local farming families. A small proportion was transitory in nature. There was ample parent help for the field trip and parents actively joined in. Comments suggested parents spent time exploring the outdoors with their children and discussed schoolwork at home. Children were friendly and appeared enthusiastic about the topic, discussing it spontaneously.

4.1.2 Class 1

Class 1 is described in Table 3.1 (p. 56). Half the class had attended only School 1. Two students were new to the school that year. One left again in the third week of the unit. All students participated actively in class discussions. At least half the class were on task all the time and three quarters or more were often on task for long periods of time. Students worked independently for long periods. Some of the highest levels of engagement were when students were involved in gathering information from books or the internet.

4.1.3 Classroom setting

Lessons took place in afternoons in a spare classroom. Students moved their desks from their normal classroom and set them up separately in girl/boy order in front of a whiteboard, as required by T1, but worked informally together. This classroom housed the school's eight computers which were networked and connected to high speed internet. Class 1 used these as an information source. There was a fixed

whiteboard at the front of the classroom used by T1 to record ideas, draw diagrams and write summaries of ideas covered in lessons which the students copied into their books. A range of teacher selected books and information sheets downloaded from the internet on the rocky shore was available on a table.

The rocky shore explored on the field trip was about 1½ hour's drive from the school at a beach where a wave platform was exposed for a considerable distance as the tide receded, enabling students to safely explore rock pools. T1 planned the trip to coincide with low tide.

4.1.4 Teacher (T1)

T1 had taught almost exclusively at senior primary level in rural areas. He had been the teaching principal at School 1 for 7 years. He normally taught the Year 4-8 class for mathematics and 'topic', in this case, science. T1 was the teacher in charge of science, a position held frequently in his career. He had no tertiary science education, but enjoyed success with science at high school. Science professional development early in his career influenced his views of science and science teaching: "I could really identify with one of the things in it, because we looked at systems and how systems are interrelated...systems all work together" (T1/I/5/3).

4.1.5 Planning for the rocky shore unit

School 1's documentation for implementation of the science curriculum included suggestions for topics to be covered each term, but: "It's very much pick out of it what you like and go with it" (T1/I/27/3). The rocky shore was not a suggested topic. Teachers wanted to build on students' enjoyment and the learning from a science unit on the sandy shore implemented the previous year: "We really want to grab the teachable moment. If the kids are really being grabbed by something, well we want to take that a bit further" (T1/I/27/3). They felt the rocky shore visit would extend students' experiences. The three teachers discussed activities and shared resources informally but met formally to plan the field trip in detail and organise equipment and risk management.

In the long-term plan for Class 1 for the term, T1 indicated the focus for the unit would be on ecosystems, interrelationships in tidal communities, interdependence, food chains, food webs, tidal zones and understanding the diversity of life at the rocky shore. He did not develop any further formal written planning but his expressed intentions correlated with the long-term plan: "Our first study's going to be about tidal communities...looking at the eating patterns of tidal communities...knowledge of

tides...and then knowledge of communities” (T1/I/5/3). Students’ understanding of these aspects, identified during the first lesson, influenced planning:

What came out today was the idea of a food chain and they’re pretty vague on that so we’ve got to do a lot of work on that. And their ideas on tides, well it’s not too bad but I want to jell that a lot more. Nobody mentioned the sun for example. (T1/I/ 5/3)

T1 signalled order and purpose to students during lessons: “Anything else on tides? Because that’s what we’re focusing on for a starter...When you talked about those four zones, we’re going to be finding what lives where in the different zones...” (T1/LT/5/3). He had a sequence in mind although no detailed written planning was recorded.

4.1.6 The rocky shore unit

An example of a typical lesson summary from this unit, developed as described in Section 3.6, is included in Appendix F. Other learning areas were not integrated with this science topic. A lesson log describing the sequence of activities and content is provided in Appendix G.

Figure 4.1 shows the time spent on learning experiences:

Figure 4.1: Time spent on learning experiences

Characteristic features of this unit were time spent in free exploration at the rocky shore, teacher led class discussion, student information gathering and copying of teacher developed summaries into books. Another feature was the use of diagnostic, formative and summative assessment with time devoted to prompt feedback. ‘Cover pages’ in Figure 4.1 shows the time given to illustrating the

heading for the topic in student books. Students used the books available to copy illustrations of relevant creatures. There was little interruption to science teaching.

The order in which science content was covered is provided in Appendix G. This order appears structured to enable students to recognise the rocky shore inhabitants they encountered during the field trip and later to use knowledge of the environment and its inhabitants when considering concepts of energy transfer.

Close examination of lesson transcripts and audiotapes showed that key science ideas in almost every instance first arose in discussion and nearly always from an idea suggested by a student. T1 managed classroom discourse so that students raised ideas freely. Written summaries were introduced only after ideas had been discussed and T1 checked for understanding as students copied them. Summaries were commonly written in the first person plural and in simply phrased language. Scientific vocabulary was a common feature. Different coloured pens were used to highlight key words or ideas.

Teacher led discussions were used prior to independent data gathering sessions to ensure students were clear about the focus for their information gathering. They were also used following information gathering making the ideas found by individuals available to the rest of the class and enabling T1 to examine the students' new understandings. These post-information gathering discussions frequently included points that he then used to direct discussion toward key science ideas. While discussions were teacher led, students shared ideas, sometimes asked questions, and contributed their own stories or examples. The overall impression was of a commonly owned goal: to make sense of the science ideas students were reading and discussing.

4.2 Teacher knowledges

This section describes teacher knowledge evident during the rocky shore unit. Domains are discussed in the order that they appear in the Teacher Knowledge Framework (Table 3.3, p. 65).

4.2.1 General pedagogical knowledge

The first component of this knowledge domain is instructional strategies and approaches. Section 4.2.1.1 describes T1's teaching approach. Section 4.2.1.2 describes sociocultural approaches used by T1, addressing both the first and third research questions. Classroom management and organisation are described in Section 4.2.1.3 and communication and discourse in Section 4.2.1.4.

4.2.1.1 Teaching strategies and approaches

T1 used a predominantly social constructivist approach, as described in Section 2.3.2.1. A key characteristic of such an approach is the identification of students' existing understanding (Bell, 2005a). Twenty minutes of the first lesson were spent in diagnostic class brainstorms that revealed students' ideas about aspects of the rocky shore suggested by T1:

The key part was finding out what they know don't know...it's about them doing stuff and rather than me being the fount of all knowledge and just telling them all the answers: I want them to find out stuff for themselves, so that's where we're sort of steering. At the moment we're identifying what they know...I want to build on that over the next 2½ - 3 weeks. They're going to go off and find out some of the things that interest them... and then we can sort of start pulling it all together. (T1/I/5/3)

These intentions are congruent with a constructivist approach: to build on existing knowledge and allow students to construct their own ideas. That information students collect would be 'pulled together' indicates social negotiation of meaning provides evidence for a social constructivist approach. Student ideas were encouraged and accepted uncritically and positively:

T1: Okay. You're going to feed that information to me. So far, you have volunteered that the tide goes in and out, that the moon is involved. What else do you know about tides?

S1: There's a high tide and low tide

T1: High tide and low tide, yeah. What else do you know about tides?

S2: It's good for boogie boarding when it's high tide

Class and teacher laugh. (LT/ 5/3)

The shared laughter typified the relaxed atmosphere conducive to suggesting ideas. T1 explained the purpose of the brainstorm to students to encourage further sharing: "See, what you already know about, there's no point in us covering that. That's what we're doing now, trying to find out what you know so then I can teach what you don't know" (T1/LT/5/3).

T1 commented on the value of students' questions for providing learning opportunities:

One of the girls came up to me and said 'Now the animals get their food from eating other animals, where do plants get their food from?' which is a wonderful question isn't it? It's just what we need! Yeah, so where *do* they get their food from? That was wonderful and I grabbed that teachable moment. (T1/ I/13/3)

T1's recognition of this teachable moment was enabled by his knowledge of key content which is discussed in Section 4.2.5.

The observation noted in Section 4.1.6 that science ideas were almost always raised first by students supports a constructivist approach. T1 emphasised to students that it was they who identified the ideas included in summaries: “It’s all stuff that you found out” (T1/LT/6/3).

T1 regularly checked the students’ understanding of the key science concepts, usually through discussion, and twice with formal assessment tasks. Immediate feedback in the form of more class discussion on key concepts followed formal assessments. This provides further evidence for a constructivist teaching model as described in Section 2.3.2.1, with its emphasis on elicitation of student understanding and conceptual development (Anderson, 2007).

T1’s approach appeared to be his usual teaching style, not one that he employed especially for science. Students seemed familiar with the pattern of lessons. Interviews with focus students suggested that he taught in a similar way in subjects such as social studies.

4.2.1.2 Sociocultural approaches

T1’s overall approach was social constructivist but several sociocultural strategies were evident. Since social constructivist teaching relies on socially mediated action, this overlap could be expected. Sociocultural strategies were analysed as described in Section 3.6. A typical lesson analysis is provided in Appendix H.

Three notable features arose from this analysis. The first is the considerable time spent in participatory and culturally scaffolded socially mediated action. This is paralleled by the use of distributed cognition. The second is the use of enculturation and guided participation strategies to initiate students into aspects of science. The third feature is the limited application of strategies relating to an apprenticeship model of learning associated with communities of practice. This raises the question of the authenticity, with relation to science practice, of tasks commonly employed by T1 in this unit. These three features are discussed in the above order.

Analysis of distributed cognition showed that students were available to each other as a thinking tool for nearly the whole time except during two formal assessment activities. Students pulled desks together to use a resource, worked together on computers, and engaged in class discussions. The ratio of computers to students, their proximity and availability of high-speed internet provided easy access to information and symbolic tools, such as tide tables, available beyond the classroom, a significant aspect for an otherwise isolated rural school. Other symbolic tools were

also readily available in the form of information from websites printed off by the teacher and topic-related books from the National Library Schools' Service. Other symbolic tools that informed discussions were the two assessment activities downloaded by T1 from the Assessment Resource Banks (ARBs), a bank of downloadable assessment activities designed for science and other New Zealand curriculum learning areas and levels (<http://arb.nzcer.org.nz/searchscience.php>). These provided examples of food chains and food webs. The final aspect of distributed cognition was the field trip, which afforded opportunities for students to explore the living inhabitants of the rocky shore in their natural setting. The provision of opportunities to encounter and investigate natural objects is an important element of distributed cognition for science since investigation and explanation of the natural world is the whole purpose of the discipline.

The availability of these tools, together with the time given to class discussion, facilitated both participatory and culturally mediated learning (Salomon & Perkins, 1998). Ideas from the symbolic tools students accessed during culturally mediated learning were shared with the whole group during discussion. In this way students were provided with access to ideas other students had found. T1 used these ideas to take the discussion in directions fruitful for science understanding. Opportunities for social mediation of individual learning were also observed. This was also used for the benefit of the collective, for example T1 would work with a student to help them find relevant information on a particular aspect, then in class discussion ask that student to share what they had found. The pronoun that dominated teacher talk was "we", further encouraging participatory socially mediated action.

The second feature of T1's sociocultural practice was the use of enculturation and guided participation to assist students with scientific vocabulary, interpretation of food chain diagrams, and the process of classification.

Scientific vocabulary that was introduced included ecological terms, or related to tides, classification of rocky shore creatures, and food chains. T1 used mutual bridging of meanings, structuring using narrative and instructional congruence to introduce vocabulary. Several strategies were often employed consecutively for the same word as exemplified in T1's introduction of the word "photosynthesis", an abstract and difficult idea. He repeated "photosynthesis" eight times altogether with six different attempts to make it instructionally congruent with students' experiences. For example:

T1: Okay have a look at this word [photosynthesis written on board] ... We've talked about this before...What does the word photo mean? I know some of you think of the word [photo] as a picture but that's actually a *photograph*. When you're talking about a picture you're talking about a photograph, but I'm not talking about a photograph... I'm talking about the first part of it now which is related to this word here [indicates first syllable] – photo. Anybody like to guess what do you need to take a photograph? What do you need?...

S1: You need light.

T1: That's the most important thing. Yes, photo means light...

T1: ...Right, photosynthesis. What does the word synthesis mean? Photo means light....All green plants, and algae, they are very clever. We've got to go and hunt for food don't we? We talk about animals have got to go and hunt for food. Well green plants don't have to hunt for food. They can make their own food. They can actually make their own food.

S2: Like we can.

T1: Well no.

S2: We can bake cakes.

T1: We can grow crops can't we and we can farm animals, but we can't actually make – yeah we can make cakes but we need ingredients, don't you? You need flour and stuff like that. Well plants, they actually manufacture their own food. So have a look, this is what photosynthesis is. Making their own food. Let's talk about those trees out there. How do plants make their own food?

S3: From the sun.

T1: From the sun, most important! (LT/13/3)

T1 referred to students' experiences in an attempt to make clear the meaning of photosynthesis and distinguish it from the way in which humans 'make' food.

T1 also used narrative to enhance understanding of vocabulary, emphasising that spring tides are extreme high tides, not low, as some students thought, using a story from his childhood.

Bridging of meanings involves mutual active interpretation and participation. An example of this occurred when a student recognised the role of the tide in bringing food to the rocky shore and T1 adopted his terminology of "new" water:

S1: It brings in fresh water for the rock pools.

T1: Fresh water?

S1: Salt water- *new* water from the sea.

T1: Okay! ... It brings in *new* water. (LT/ 6/3)

T1 introduced the food chain, a scientific diagram representing energy transfer through structuring students' direct interaction. He first presented students with a simple food chain consisting of rocky shore creatures for which they knew the eating habits. Students, however, struggled with the meaning of the arrows which they

interpreted to mean “eats” rather than showing energy transfer, an outcome not unexpected by the teacher. He then drew an example more common to their experience as children in a dairy farming community: sun → grass → cow → human:

T1: Is that how energy is transferred?

S1: Yes. Because we eat the beef and we make them fat by giving them grass and the grass soaks up the sun to make it grow. (LT/13/3)

He then moved back to the rocky shore context, introduced more complex food chains, and later explored food chains in a different context. Structuring of interaction moved from familiar to more familiar, to more complex and then to a completely new context. The content knowledge needed to be able to move responsively and fluidly through these steps is considerable and is discussed in Section 4.2.5.

T1 introduced students to the scientific process of classifying living organisms. Again the interaction was structured: students were first guided to describe the different classes of creature that live at the rocky shore together with named and drawn examples, then during their time at the rocky shore they located and identified the creatures they found. T1 also provided an informal example of expert practice in classification showing that classification involves possession of a set of specific features. The informality of this enculturation into classification continued at the rocky shore where students were free to wander and explore. T1 moved between groups enjoying their discoveries, gently questioning but not forcing them to identify creatures.

T1 used sociocultural strategies to support his social constructivist teaching approach, but there was also an indication from interviews of a more sociocultural belief about science teaching. When asked what he thought children needed to learn about science at primary school, T1 responded with a family story that illustrated an apprenticeship model of learning through authentic practice. A later interview supports this: “This is science, you know, pure science, where you learn to do your own research. Go out there and do it. You know, get out there and go to the rocky shore” (T1/I/27/3).

This implies a belief in an apprenticeship approach where students learn by engaging in investigation of the natural world, a practice T1 perceived to be characteristic of science. However, the rocky shore visit was the only real opportunity for such participation. The joint enterprise in which students were most

frequently engaged was the understanding of science ideas. This aligns with approaches described in Section 4.2.1.1 and T1's orientation to science teaching (Section 4.2.7). Understanding was iterated as a goal several times during lessons: "When we finish this study, we've got to make sure that we all understand this, okay?" (T1/LT/5/3); "So that's very important - that you know that about energy transfer" (T1/LT/13/3); "It's very important that you get that notion of the food chain" (T1/LT/27/3). In order to understand ideas, the students were engaged in gathering and interpreting information from books and the internet. That students joined in the enterprise of understanding key concepts was demonstrated by their levels of engagement, contribution of ideas, and sense making:

T1 (recapping the written summary children are copying): You've got energy transfer that always starts off with the producers doesn't it, or the detritus which is dead stuff that whelks like to eat-

S1: And seagulls. [interrupting]

T1: Seagulls, yes. It's good isn't it? When an animal dies other animals can live off it and it cleans it all up again.

S2: So the ocean is clean!

S3: If we didn't have scavengers, the world would be covered in smelly, disgusting stuff. (LT/ 27/3)

The teacher affirmed and used students' contributions. For example, a diagram of tidal zones found by one boy was copied for everyone. While T1 demonstrated knowledge of ways to encourage and foster a sense of joint enterprise amongst his students, that enterprise was understanding substantive science knowledge. Symbolic tools were regarded as the authority. This may have encouraged a student view of science as a set of ideas to be understood. Students' perceptions of their learning are discussed in Section 4.4.

To summarise, T1 used a range of sociocultural strategies. The joint enterprise that developed was the understanding of substantive science knowledge; however students were also enculturated into the authentic practice of classification and use of scientific diagrams and vocabulary.

4.2.1.3 Classroom management and organisation

Figure 4.2 shows the frequency of use by T1 of components of this knowledge. The time spent on appropriate tasks was shown in Figure 4.1. The major features of this analysis are presented and discussed below.

Figure 4.2: Frequency of observed use of knowledge of classroom management and organisation by T1

Only one experience was organised in small groups, the small class size perhaps reducing the need for formal group work. Few interruptions to science lessons were observed and as they all involved logistical organisation for triathlon practice following science these were classified as “awareness/multiple tasks” in Figure 4.2. A low frequency and duration of problem resolution and low need for consequences demonstrates that T1 maximised the time spent on science related tasks. Contributing to this was his ability to build a sense of joint enterprise, as discussed previously. High frequencies for setting clear expectations and providing feedback, nearly all of which was positive and affirming, added to this participatory culture.

The almost constant monitoring of student performance using interactive dialogue during class discussion, formal assessment tasks, and checking individuals as they worked, contributed to T1’s awareness of individuals’ understanding and interest. He frequently linked to students’ prior knowledge, ideas covered in earlier science units, or, as the unit progressed, ideas covered earlier in the unit. This contributed to development of new ideas, e.g., using knowledge of feeding habits to interpret food chains.

Structuring of new information was evident in the way T1 focused discussion or information gathering on particular aspects of the topic at different times:

I’m going to set you off to look at some resources to see if you can find answers to these questions because in our study on tidal communities the thing that we want to really zone in on is tides. What are tides? How do they work? Where are they? When and why [do they occur]? (T1/LT/6/3)

In focussing discussion, T1 often indicated the value of aspects raised by students and signalled that they would be useful later.

4.2.1.4 Classroom communication and discourse

Valuing and working with students’ ideas is characteristic of an interactive dialogic communicative approach, an approach used constantly by T1 in class discussion. There were only a few very short instances of other communicative approaches: at the beginning of the first lesson T1 used a mix of interactive authoritative and dialogic approaches to direct the discussion to the nature of science in a way that made it clear that this was a science unit. Occasionally T1 used short bursts of authoritative non-interactive discourse to summarise and restate science ideas that had been discussed: “Well, we’ve sort of got that into our heads, people. The tides occur twice a day. A spring tide occurs every fortnight and then neap tide, every fortnight as well. A spring tide’s really high. Neap tides, they’re very low” (T1/LT/7/3). No examples of dialogic non-interactive discourse were observed. T1

managed the discourse by narrowing or broadening the focus of his questions and structured the discourse by providing a focus for contributions as described previously.

T1 used general pedagogical knowledge to teach science concepts. In particular he demonstrated knowledge of ways to manage discourse and develop a sense of joint enterprise in order to achieve the socially constructed learning he valued.

4.2.2 General aims, purposes and values of education and assessment

T1's educational aim was for his students to become independent learners. He linked this with use of information technology:

Just to become independent learners, really that's what our aim is, that when they leave this school and go off to high school, they have all the wherewithal, the skills in particular, and the attitudes too of course, and the knowledge, which they build on, ready for high school, learning to find out things for themselves, and this is why we've spent a lot of money on computers. (T1/I/5/3)

For T1 it seemed being independent learners meant being able to use technology to find information. This fitted within his constructivist teaching approach. When linked with T1's frequently stated goal of understanding science ideas, it may explain the high proportion of time spent gathering information during this unit, despite beliefs about the importance of practical work in science.

The goal of creating independent learners was part of a larger purpose, to adequately prepare students for high school, as emphasised in lessons:

When you get to high school you'll be doing a lot more of this [copying notes from the board] so it's good practice....You're going to be high school students soon....Nice, neat work, that's good: you'll be ready for high school by the end of the year. (T1/LT/6/3)

T1's practice indicated that he understood the value and purpose of informal and formal assessment to be in informing future teaching. Interview data support this:

I normally like to start off either maybe with a barrier activity or concept map or something like that and then we do a lot of brainstorming, just drawing out from the kids what's already there. Then we draw out what we already know and then [I know] in my own head they know this or they're a bit vague on that.

The ARB that I ran off [I will use] more or less at the end just to check up on knowledge gained and how accurate it is. You know, so if they get a lot of it wrong, well then, maybe, you know, we want to re-teach it... [It's] information for me, just to find out what they've learned from it. (T1/I/6/3)

Barrier activities involve students in listening and interacting together but without seeing what other students are doing. T1's comments and observations of his practice indicated that the material included in lessons was developed in response to informal and formal diagnostic and formative assessment. For example, following the initial assessment activity on food chains, T1 introduced further material on the tide as a source of food, discussing the role of zooplankton and phytoplankton as well as detrital food chains (Appendix G).

The use of structured assessment tasks before and after teaching about food chains indicates knowledge of assessment for showing progress and that growth in substantive knowledge was used for this purpose in science. The immediacy of feedback provided after each assessment task also suggests knowledge of its importance for learning.

4.2.3 Learning and learners

T1's view that students should learn for themselves formed a significant part of his beliefs about the way students learn and was reflected in his teaching approach as described in Section 4.2.1.1.

Student interest and engagement was seen as significant to learning: "I think it's very important that kids learn about things that interest them. Because if you haven't got their interest...it's no good talking about dead boring stuff!" (T1/I/27/3). He believed that Year 7 and 8 students enjoyed more complex ideas than the younger students normally part of his class: "I mean I wouldn't talk about photosynthesis or anything like that with Year 4, but they [Yr7 & 8s] enjoyed that" (T1/I/27/3).

T1's beliefs about learners of this age group included that they enjoyed practical work. He believed that practical work assisted learning, linking it with increased engagement of the senses:

Kids always love experimenting, especially when you get test tubes and you get some crystals and a bit of hype: lots of practical stuff, not enough as far as they're concerned!! They love it....I just think you learn so much more from hands on than you do from being told something or rather, being told only goes to one sense: you're better to use all their senses. So the more senses you use the more it's going to sink in. So really, that's the theory behind that. (T1/I/5/3)

These beliefs, together with views previously described in Section 4.2.1.2 concerning learning through participation in investigation, make it more surprising that practical work did not take greater precedence in the observed unit. The

distance of the rocky shore from the school may have been restricting. The above statement suggests T1 regarded practical work as an aid to understanding rather than of value in its own right. His views about the importance of students having an accurate summary of ideas prevailed throughout:

I generally like writing a summary and they copy that from the board. That may be my old school idea, but I like that because they've got a record of what we've got. Parents can see what they've done too and I encourage them to keep that for future years rather than biffing their books. So I think there's a place for that. (T1/I/5/3)

Other personal learning theories about this age group related to behaviour management and had developed from experience:

Normally I sit them boy girl boy girl and I've always found that, it's my experience, that they learn the best that way. They don't get silly and poke each other like they sometimes do. If you sit them that way it makes them far better on task. (T1/I/5/3)

We haven't had bad weather, windy like this, for a long, long time. I was a bit annoyed with the boys, how flighty they were. And they're really not like that. Well, after a long hot summer and it's the first wind. (T1/I/13/3)

4.2.4 Educational context

T1's knowledge of governance and budgeting was beneficial for science and for this unit:

We talked about it [last year] with the Board of Trustees. We said next year we might go to the rocky shore and we want to buy some materials for it so we think we need, about \$300 odd should cover it. [This was for] equipment, whereas science books, books would come under the library. So that's mainly equipment in science. (T1/ I/29/3)

Students used equipment such as magnifiers, fishing nets and sample boxes on the field trip. The science budget was used for equipment, books coming from a separate budget.

T1 used his knowledge of school financing to organise staffing so Year 7 and 8 students formed a separate class for this unit, enabling him to work with them in more depth. This action perhaps reflected his knowledge of the school community, recognising that the part-time teacher was not strong in science and that he himself was more able to meet the needs of the senior students in this area.

Knowledge of his students' needs and interests meant T1 instigated the formation of the separate class as well as the selection of topic, based on their enthusiasm for the sandy shore unit as described earlier. Some students saw this as repetition however, so his knowledge of students' interests may not have been as well

grounded as he thought. Knowledge of individual students was frequently drawn on. This is illustrated by T1's work with a student (A) with a history of poor literacy. During information gathering sessions T1 would quietly make sure A had appropriate texts and was clear about the focus. His knowledge of individual accomplishments later enabled him to celebrate A's skill in drawing. Similar instances occurred with a student new to the school who had trouble settling to work. T1 used his knowledge of information this student had gathered to cast him in the role of expert to the class for that aspect. Another new student was similarly acknowledged, thus encouraging their participation in the group's enterprise. This affirmation of students was part of T1's knowledge of classroom management. It depended on knowledge of individual students and content knowledge enabling recognition of contributions useful for science; it demonstrates integration of a range of knowledges.

T1 drew on his knowledge of the students' experiences as part of a dairy farming community when developing the idea of energy transfer through food chains as described in Section 4.2.5.2. Introducing a local example enabled several students to make meaning from food chain diagrams and facilitated further discussions about the flow of energy and the importance of the sun and plants. This was not a planned example and demonstrated how T1 was able to spontaneously integrate his knowledge of students with content knowledge.

Knowledge of the New Zealand community, in particular its bicultural heritage, was not predominant in this unit. Commonly used Māori names for rocky shore creatures were used in one lesson by T1. This appeared to be an act of establishing cultural congruence, ensuring students linked everyday terminology with scientific classification and vocabulary rather than a culturally responsive strategy.

4.2.5 Science content knowledge

T1 displayed considerable science content knowledge in implementing this unit. Useful syntactic knowledge and beliefs were expressed and substantive knowledge in all categories was apparent.

4.2.5.1 Syntactic knowledge and beliefs

T1 believed science to be a changing body of knowledge, suggesting that improved technology effects this change:

Some things that we've always thought were fact, as time goes on, things change, the more you find out about it: that's really the nature of science isn't it, things change! ...Years ago they said Napoleon died of a broken

heart and nowadays they say, no look we've got a lock of his hair and we've done tests and they show that he died of arsenic poisoning...so what we perceived as "fact" we're now delving more and more into it with forensic science and we're finding hey that wasn't quite right. So it's more open ended. (T1/I/6/3)

He believed that science involved a process:

I really wanted to get that feeling through that science is not just knowing about test tubes, but more that there's a process involved. It's a process approach which we're going to be doing. That's why we're going on the field trip: we're going to be doing things. (T1/I/5/3)

Science is very much a process: not just a fixed body of knowledge, and I say to the kids you've got to find out for yourself, you know. Don't be swayed by somebody's opinion, especially when people try and say that 'I am right and this is the way it is.' You've got to have that inquiry spirit, you see. You've got to go and search things out for yourself. (T1/I/6/3)

Science is experimenting. Yes. Doing, that's more like it. Experimenting, researching. That's why the school bought the computers that we've got and broadband. (T1/LT/5/3)

While T1 wanted his students to critically consider claims, during the unit information from books and computers was accepted as authoritative. As indicated in the final excerpt, the scientific process of knowledge creation and critique was confused with, and subsumed into, the process of gathering information and understanding substantive science knowledge.

4.2.5.2 Substantive knowledge and beliefs

The knowledge of general concepts and principles exhibited included the Linnaean classification system, energy transfer through ecosystems, and adaptation to habitat. T1 related topics to other science disciplines, introducing chemical equations for photosynthesis while emphasising the role of producers in releasing oxygen.

T1 held a view of substantive science knowledge as a series of interrelated systems as described in Section 4.1.4. This belief was apparent in his aim for the rocky shore topic: "[I want them to get] an understanding of how all life is interrelated really... that's the really the big idea in this thing" (T1/I/5/3).

He included this view in lessons, applying concepts across contexts:

T1: Isn't it interesting about the cycle of life? And it is the same with you people now, if you die, we become food don't we?

S1: Yea for maggots!

T1: Our body gets broken down

S2: But what if you get burnt or cremated?

T1: Well then it is different, we turn into ash but what is ash used for?

S3: Cleaning windows

S4: I thought we keep the ashes?

T1: Some people like to have their ashes spread across the field or ocean so it becomes fertiliser to help new things grow, quite fascinating. So it is sort of a cycle there then? Dead stuff is eaten as it decomposes, by fungi and bacteria and animals such as mud worms: that's those little tiny worms at the rocky shore that we saw. (LT/29/3)

T1's knowledge of general concepts was supported by detailed topic-specific as well as non-target content knowledge that enabled him to move across contexts, depending on the turn taken by the discussion, maintaining a focus on common concepts within them.

Topic-specific content knowledge exhibited by T1 included: effects of the sun and moon's gravitational fields on tide patterns, names, characteristics and examples of the classes of rocky shore animals, examples of organisms from different trophic levels in a variety of contexts, and an understanding of the complexity and variety of energy relationships, e.g., detrital as well as producer-based foodwebs.

T1's teaching drew on a wide range of detailed topic-specific and non-target content knowledge guided by knowledge of general concepts and principles.

4.2.6 Curriculum knowledge

The general aim expressed by T1 that his students become independent learners reflected one of the principles of the then current *National Curriculum Framework* (MOE, 1993b). Encouraging students to locate substantive science ideas for themselves aligned with the direction of this principle that the school curriculum "foster the development of knowledge, skills and attitudes that will empower students to take increasing responsibility for their own learning" (MOE, 1993b, p. 7). Whether or not T1's aim derived from knowledge of this document or simply aligned with it was not established.

T1's expressed beliefs about implementation of *Science in the New Zealand Curriculum* (MOE, 1993b) seemed at odds with the reality of his classroom practice. He stated the importance of its two integrating strands in determining what was important to teach in science:

It's the integrating strands. You know a lot of schools have gone for the contexts, rather than the integrating strands. It's this Nature of Science and Developing Skills and Attitudes and that, they're so important... for me anyway. The context is for you to learn those things. (T1/I/5/3)

This view foreshadows the emphasis on the Nature of Science strand in the 2007 curriculum (MOE, 2007). However, when asked later in the same interview what he thought about when planning for science, he focused on the contextual strands: “I think more about, obviously the living world or planet earth and beyond, so focussing on those: the strand. So that’s really going to be the focus, like now it’s the living world, so, tidal communities” (T1/I/5/3).

The long-term plan supports this latter emphasis. T1’s learning intentions, as described in Section 4.1.5, link closely to objectives from the Living World contextual strand from the 1993 curriculum:

At Level 3 students can:

- distinguish between living things within broad groups on the basis of differences established by investigating external characteristics
- explain, using information from personal observation and library research, where and how a range of familiar New Zealand plants and animals live. (MOE, 1993a, p. 58)

At Level 4 Students can:

- investigate and classify closely related living things on the basis of easily observable features
- use simple food chains to explain the feeding relationships of familiar animals and plants, and investigate effects of human intervention on these relationships. (MOE, 1993a, p. 60)

T1 provided experiences that related directly to achievement levels and objectives, but contrary to his expressed beliefs, their focus was on the contextual strands rather than the integrating strands.

Knowledge of vertical curriculum impacted on what happened in this science unit. Knowledge of topics the students had already covered was used in topic selection. T1 linked to previous science studies to build on ideas such as photosynthesis. Beliefs about higher levels of curriculum, perceptions of learning at high school, were used as justifications for students recording accurate, tidy notes and learning to find information.

Knowledge of the horizontal curriculum was not expressed or apparent in the teaching of this unit. T1 once stated that copying the science notes would be handwriting practice for that week, but no expectations or teaching regarding handwriting occurred. He suggested that some past science units had been more integrated with other learning areas. The lack of connection to other learning areas

may have been a result of T1's role as principal: his teaching of Class 1 was restricted to science and mathematics.

T1's knowledge of resources was wide-ranging. The *Building Science Concepts* booklet about tidal communities (MOE, 2002) provided background teacher reading. The internet was T1's main source of science information. Games and information for students were obtained from the local museum. A range of children's books selected by T1 specifically for his students came from a collection ordered by the school from the National Library Schools' Service. Magnifying sample boxes and nets had been purchased especially for the field trip. A digital camera belonging to the school was also used. T1 knew where and how to obtain resources. His beliefs about what it was important to cover, content knowledge and contextual knowledge of students then influenced his selection of resources from the available pool.

4.2.7 Science pedagogical content knowledge

T1 displayed an academic rigour approach to science teaching in this unit. This approach emphasises understanding the body of scientific knowledge. Practical work is used to support scientific concept development (Magnusson et al., 1999). This was the case here: the field trip consolidated concepts developed in class. T1's frequently stated goal of understanding key concepts and the time given to information gathering and monitoring conceptual understanding emphasise the dominance of this approach, despite his stated belief that the purpose of science at Years 7 and 8 was to help students understand science as a process that involved experimenting and critical consideration of claims, as described in Section 4.2.5.1.

Use of representations was the main aspect of knowledge of science instructional strategies demonstrated by T1. He used models to show the gravitational effects of the sun and the moon on tide patterns on Earth. Food chains and webs were used to represent energy transfer through ecosystems. Additionally, he used an ordering activity suggested in one of the internet resources to introduce detrital food chains, an example of use of activities that work (Appleton, 2002).

T1's knowledge of how and what to assess in science aligned with an academic rigour approach. He monitored students' conceptual development. His content knowledge was significant here, as he checked for understanding of concepts and principles rather than regurgitation of facts. That food chains were the subject of formal assessment may reflect curriculum knowledge as these were the focus of Level 4 achievement objectives.

T1's use of assessment focused on development of substantive rather than syntactic knowledge. School-wide assessment data for science collected by T1 for use in school review reflected this focus.

T1's knowledge of student difficulties meant he anticipated students' problems in understanding the direction of arrows in food chain diagrams: "Now listen, don't feel bad about it because 99% of children and probably most adults too would think that. They all start off with the person and have it coming down. It's actually the opposite" (T1/LT/13/3). His assessment and subsequent teaching drew on this knowledge. As well as recognising this common misconception, T1's monitoring built awareness of individuals' confusions and strengths, an awareness again facilitated by his substantive knowledge.

4.2.8 Summary of teacher knowledges evident in the unit

T1 demonstrated knowledge from each domain. He integrated a range of knowledges and beliefs in this unit. His social constructivist approach drew on strong general pedagogical knowledge including effective classroom organisation and management of interactive discourse. An academic rigour orientation combined with a strong belief in the importance of information skills dominated the unit, despite beliefs about the significance of practical work in science for learning. Because of his orientation to teaching science, T1's substantive science content knowledge, used in conjunction with other knowledges, influenced the provision and nature of science learning opportunities.

4.3 Development of teacher knowledge

His academic rigour orientation to teaching science meant T1's substantive science content knowledge was critical. His orientation appeared to limit him to teaching familiar topics: "I probably don't teach topics that I'm not confident in: I choose my topics" (T1/I/6/3).

Although T1 had not undertaken professional development in science since the implementation of the 1993 curriculum, the 'systems' view of science knowledge introduced then strongly influenced his thinking as indicated in Section 4.2.5.2. He commonly drew on knowledge of general concepts and principles. When questioned about his science knowledge he referred to his secondary schooling. The interest and enjoyment of science he developed there remained and he read about science related topics for interest: "There's always stuff that comes up that's interesting. That's why I love my holidays because that's when I really get the time. I love nothing better than to go away...I always take a stack of books with me" (T1/I/6/3).

He built content and resource knowledge through reading *Connected*, student reading resources focused on science, technology, and mathematics, in journal format provided free to schools by the MOE. “I need to go through them every time they come so I build up my own knowledge of what’s there” (T1/I/5/3).

Reading therefore sustained and developed T1’s background science content knowledge. However, when preparing for a science unit he deliberately updated and refreshed the detail of his topic-specific content knowledge, mainly using the internet: “I always try and prepare myself for whatever the unit is, you know. It’s really good to refresh your memory...it’s good to just do that background reading again....The internet: it’s a big tool that I like using” (T1/I/5/3). In this way he built both new PCK, knowledge of activities for a topic such as the food chain ordering activity used in this unit, and substantive knowledge.

In summary, T1’s views about science knowledge developed early from professional development. His interest in science meant he read widely, building background content knowledge. He read and used the internet to check his substantive knowledge, sometimes locating relevant activities, before teaching science.

4.4 Student perceptions of learning

The final research question for this study concerned the influence of teacher knowledge on students’ perceptions of their learning. An analysis of the data gathered for this case concerning students’ perceptions of their learning is presented in this section. Student questionnaires and focus student interviews were analysed as described in Section 3.6. The analysis of questionnaires is presented in Section 4.4.1 and that of focus student interviews in Section 4.4.2.

4.4.1 Whole class questionnaires

Student post-questionnaires showed that all students thought they had learned ‘quite a lot’ from the rocky shore unit (N=7). They were not quite as positive regarding enjoyment (Figure 4.3).

Figure 4.3: Responses to student questionnaire, Q.11 & 12: Utility and enjoyment

Responses shown in Figures 4.4 and 4.5 reveal interesting comparisons between student enjoyment of activities and perceived utility for learning.

Figure 4.4: Responses to student questionnaire, Q.8: Student enjoyment of rocky shore unit activities

Figure 4.5: Responses to student questionnaire, Q.8: Student perceptions of utility for learning of rocky shore unit activities

All students enjoyed the field trip, and most felt it was very useful for their learning. All but one disliked copying summaries from the board, but all students thought it useful or very useful for their learning. Only one student really enjoyed finding information from books, others rating it 'ok', but four found it very useful for their learning and the other three useful. A similar contrast between enjoyment and utility rating occurs for both activities on food chains. Class discussions were seen as enjoyable or 'ok' by all students who also found them 'very useful' or 'useful' for their learning. The focus in class discussions was substantive.

Responses concerning new or interesting personal learning included conceptual and empirical learning: "a lot about sea anemones and plankton", "how the moon and the sun pull the tides in and out", "shrimps are fast and you can see through them" (Student post-questionnaires, Q1). More general responses indicated learning concerned rocky shore creatures and how they live. Figure 4.6 shows that when provided with a list of concepts covered in the unit, four students felt their most successful learning was about eating habits and energy transfer. Five students reported improved understanding of the causes of tides and four of food chains. Responses indicating lack of understanding of the ideas came from only two of the students. Four students felt they knew a lot about classification already.

Figure 4.6: Responses to student questionnaire, Q.10: Student perceptions of learning given concepts/skills

Six students thought T1 was quite effective and one thought him very effective in teaching the unit. Students did not identify specific detail in suggesting what they thought their teacher wanted them to learn from the unit: five of six responses suggested life at the rocky shore generally; one suggested tides and the different animals; one also included dangers, predators and prey. Most teacher actions were valued to a certain extent by all students (Figure 4.7).

Figure 4.7: Responses to student questionnaire, Q.9: Student perceptions of utility for learning of teacher actions

The action valued most highly was getting students to share information they had found, followed jointly by ensuring students had books they understood containing relevant information, and using models. Teacher explanations of various kinds were also valued quite highly.

To summarise, students enjoyed the field trip and believed it useful for learning; they valued sharing information and explanations and saw copying summaries and finding information in books as useful for their learning even though they were not enjoyable. This analysis suggests a general student perception that learning science meant understanding substantive science knowledge. The role the field trip played in their perceptions of learning was explored with focus students and described in the following section.

4.4.2 Focus student interviews

Details of the four focus students are provided in Table 4.1.

Table 4.1: Case 1 Focus Students

Student	C1FS1	C1FS2	C1FS3*	C1FS4*
Year	7	8	8	8
Gender	Female	Male	Female	Male
Ethnicity	NZ European	NZ European	NZ European	NZ European
Interest in science	Moderate	Moderate	Moderate	High
Time at School 1	7 years	8 years	4 years	4 years

*C1FS3 and C1FS4 were twins.

C1FS1 was highly motivated to read for herself about the topic and contributed often to class discussions, sharing information and raising thoughtful questions and ideas. C1FS2 was frequently fully engaged in experiences and was keen to learn as he wanted to be well prepared for high school. C1FS3 expressed less interest in the rocky shore topic as she had studied it at a previous school and felt she was repeating work. C1FS4 was highly interested in science, although less so in this topic. He felt strongly that science should be a practical subject; he did not enjoy copying from the board but enjoyed and engaged with independent research, particularly using the computer. All four students displayed moderate to high levels of on-task behaviour.

Student responses about their learning are summarised in Appendix I. All aspects of learning described by students were substantive. The important learning students identified reflected concepts emphasised by T1. C1FS2 said he worked hardest on

understanding, reflecting T1's frequently stated goal. Interviews revealed depth of learning:

The high zone can get food just from around there, and the low zone, they're like mussels and things, they need to be fed from the fresh [sea] water, but I guess the tide comes in and brings food to all of the life on the shore...[high tide zone animals] they might get eaten by the birds and the food might come later, not for as long, the water won't be there for as long. (C1FS2/ 1/29/3)

C1FS2 indicated that the field trip confirmed other learning and that seeing things in real life helped understanding:

You write it down and hear about it then you actually go and get to see and look at it. If you went to the rocky shore first you wouldn't really know what anything is...It's better to see it in real life than just see it in pictures...It helped understanding of it as well, like understanding what they do and how they do it, and you could actually see them do it and stuff...like the chitons, when they move along the rocks. Like, it's kind of hard to imagine how they would do it, but then you see them. (C1FS2/1/13/3)

When asked if they learnt to do anything new or got better at anything to do with science, students said:

I found that you got to be careful, with handling the creatures, holding them...Coz otherwise if you like don't put rocks back in the right place they might get – dead. (C1FS1/1/29/3)

Just care for the life there and make sure you put the rocks back in the exact places that you found them...coz you disturb the life there, they have to find a new home and things, and they've already got their home. (C1FS2/1/29/3)

I got better at knowing where to find things...Like seeing where the animals live: like the sea anemones, they mostly live hidden. (C1FS4/1/29/3)

The care expressed for protection of living things was unexpected as this had not been a focus of observed lessons but students said T1 had emphasised this at the field trip. No syntactic knowledge development was identified, although C1FS4's comment highlights the interrelationship between knowledge and observation.

To conclude, students' perceptions of their learning were largely substantive. The concepts they identified as their learning correlate with concepts identified as important by T1. Their substantive view of learning, together with their perception of the field trip as confirmatory, reflected T1's academic rigour orientation to science teaching. T1's substantive science content knowledge, his understanding of principles, systems and topic specific detail, was reflected strongly in students' perceptions of learning:

Dead animals, plants, and plankton could be a producer...If there's no producer then everything would probably die...that was probably most important, the food chain: it's the life cycle of everything basically. (C1FS4/1/29/3)

4.5 Summary

This chapter presented findings for Case 1. T1 drew on knowledges from all domains in implementing the science unit. His aims for students and beliefs about the nature of independent learning influenced the nature of learning opportunities in science as did his orientation to teaching science. Opportunities for science learning focused almost entirely on development of syntactic knowledge. His considerable content knowledge was therefore a considerable influence. T1's view of science as explaining the world in terms of interconnecting systems, developed from early career professional development in science, influenced opportunities for science learning. He read and used the internet to develop his science content knowledge. Several sociocultural practices were used to support a social constructivist teaching approach. Student perceptions of their learning were substantive in nature.

CHAPTER 5

Case Study 2

5.1 Setting

Case Study 2 comprised T2, a syndicate leader and teacher in charge of science in a large intermediate school, implementing a unit on science fair investigations with her class of 30 Year 8 students. Each class at School 2 undertook a similar unit culminating in a biennial school science fair which had a high profile in the school community. A panel including practising scientists and science teachers from a local high school judged the exhibits. Those selected from this fair represented School 2 in the regional competition.

T2's teaching of the unit was interrupted twice by illness and at the end for the practicum of a teaching student. T2 supported the teaching student but did not formally teach. Only science lessons taken by T2 were observed. Four of T2's ten science lessons were unable to be observed by the researcher (Table 3.1, p. 56).

5.1.1 School 2

School 2 was situated in a large suburb. Classes mostly comprised either Year 7 or Year 8 students and were organised into three syndicates of six closely located classes. All teachers were participating in professional development in thinking skills at the time of data collection.

5.1.2 Class 2

Class 2 is described in Table 3.1 (p. 56). Individuals were involved in sport or cultural activities that sometimes took them out of class during science lessons. Timing for science often deviated from that planned because of school events. These interruptions were normal at School 2: "The kids are busy and broadening their interests in all sorts of ways. We moan and groan it's too much, but we like all the opportunities they have; that's why we're here" (T2/FN/18/5).

Engagement levels were moderately high: three quarters of the class were on task for most of the time. Higher levels of engagement were observed for practical and group activities than class discussions. A few students consistently engaged in all science activities and discussions enthusiastically. One student with severe learning difficulties had a full-time teacher aide working with him in class. His involvement in class activities was supported and encouraged by T2.

5.1.3 Classroom setting

All lessons were in Class 2's classroom. Students worked at desks in groups of four to six. The class sat together on the floor for discussions and demonstrations. A large whiteboard at the front provided the day's timetable, notices and reminders. It was used to display learning intentions, record ideas, information and instructions or display examples during lessons. Student work decorated the walls. There were two networked computers in the room. T2 used a networked laptop. A computer suite in a dedicated teaching space was available, but students mainly prepared reports of science fair investigations at home.

5.1.4 Teacher (T2)

T2 had previously taught for three years in Year 5-8 classes in a large suburban full primary school where she was teacher in charge of science. She had been at School 2 for five years, becoming a teacher in charge of science with another teacher in her second year and a syndicate leader a year later. T2 had no tertiary science education, but enjoyed science at high school.

I don't have a great deal of knowledge in science but I enjoy it and I do feel passionate about teaching it. I love it, because I'm interested in it and I think maybe when you're interested in something you enjoy teaching it. (T2/I/18/5)

T2 had not undertaken formal professional development in science but was influenced by a previous teacher in charge of science: "for the first couple of years really we did the job between us. She very much mentored me in taking on the role" (T2/I/18/5). This was T2's third time teaching a science fair unit at School 2.

5.1.5 Planning for the science fair unit

T2 and a less experienced teacher led science in the school. The school implementation documents suggested coverage of two science contextual strands each year. The science fair unit provided coverage of the integrating strands of the science curriculum (MOE, 1993a), although a fair testing focus prevailed in other science units: "we try and incorporate fair testing with our other units in the school... we've done two strand units a year and we've focussed on fair testing as part of that" (T2/I/18/5).

T2 and the other science leader led a staff meeting focused on science fair planning in preparation for the unit. Planning was presented as a sequence that teachers could adapt: "we've learnt from the past that the nature of this type of unit is you just have to go with the flow and plan as you go based on needs" (T2/I/14/6). The planning was altered to be less contextually based than in the past:

We always tried to do a knowledge strand and teach fair testing at the same time, so you had a real, gutsy base to start with, and you had a context for starters, and then everything else sort of fell into place. Having it as an annual event was too much, too stressful, so we did an extensive review: students, staff, parents. That's why this year it was decided to do it from a different angle, to free it up a bit and leave it to be quite open, so you don't have to come up with a context *and* fair testing. (T2/I/15/5)

Topics in English and statistics had been scheduled specifically to support the science fair unit.

5.1.6 The science fair unit

An example of a typical lesson summary from this unit, developed as described in Section 3.6, is included in Appendix J. The summary shows a repeated teaching pattern characteristic of this unit: teacher modelling or explanation of a step in the fair test investigation process followed by group or individual practice of that step. Students later used these steps in developing their own science fair investigation and display, an activity largely carried out in their own time at home. A specific feature was the provision of explicit success criteria for each step. For example:

WILF: What I am looking for:

1. A question which is open ended (why, when, what, where, who or how)
2. A question that is specific and can only be answered by observing, testing, measuring of data and experimentation
3. A question that is focused on one aspect (For example instead of writing "Does mould grow on bread?" Try "How does light affect the reproduction of bread mould on white bread?") (Class Handout, FN/21/5)

T2 facilitated student achievement of these criteria through example and practice. Where student achievement did not initially meet the criteria a step was revisited with further practice opportunities. This teaching pattern, including the large proportion of time spent on modelling and practice, is reflected in Figure 5.1.

Figure 5.1: Time spent on learning experiences

Emphasis was on planning a fair test: developing a testable question, developing a scientifically reasoned hypothesis and controlling variables. Students carried out three practical fair tests in class during the unit but not all were observed. Each of the fair tests focused on a different key step: controlling variables, recording results methodically and developing a conclusion. Students carried out practical work for their individual science fair investigations at home. Later unobserved lessons focused on the nature of scientific conclusions and peer and self-evaluation of investigations.

Appendix K records a lesson log summarising the order in which science content was covered. Contexts used for learning are given in brackets under the major topic. The high degree of repetition of different steps in the investigation process is evident.

5.2 Teacher knowledges

This section describes the aspects of teacher knowledge evident during the science fair unit. Domains are discussed in the order that they appear in the Teacher Knowledge Framework (Table 3.3, p. 65).

5.2.1 General pedagogical knowledge

The first component of this knowledge domain is instructional strategies and approaches. Section 5.2.1.1 describes T2's teaching approach. Section 5.2.1.2 describes sociocultural practices used by T2, which also addresses Research Question 3. Classroom management and organisation are described in Section 5.2.1.3 and classroom communication and discourse in Section 5.2.1.4.

5.2.1.1 Teaching strategies and approaches

T2's approach can be characterized as primarily sociocultural because of significant use of many of the elements of such practice: socially mediated action, situated and participatory activity including use of authentic activities, staged tasks, provision of examples of expert practice, enculturation and guided participation. This categorisation is supported by T2's views about how learning occurs, stating that both participation and socially mediated action are significant:

Kids learn by doing and by discussing: all of the conversation that happens around a group activity is relevant. And if you can provide opportunities then for discussion afterwards, to draw in, share some of those discussions, then that's powerful as well. (T2/I/18/5)

A detailed description of T2's sociocultural approach is provided in Section 5.2.1.2.

The classification of T2's approach as sociocultural was not straightforward. It is notable that the sociocultural practices applied by T2 were used to bring students to a specified level of competency. There is an overlay of what seems to be almost a mastery or developmental approach, exemplified by the breaking down of the scientific investigation process into its composite steps and the practice of each step until T2 felt students could meet her clearly stated expectations: "I haven't given you that yet because you're not ready for that stage. You're still at this stage, which needs to be completed before we go onto the next stage" (T2/LT/15/5).

The expectations set relied on T2's personal understanding of scientific investigation. She limited students' experience of scientific investigation to fair testing methodology, rather than extending it to include other forms of investigation such as exploration and pattern seeking (Goldsworthy, Watson, & Wood-Robinson, 1998; MOE, 2007). This limitation may indicate a gap in T2's syntactic knowledge, and is discussed in more detail in Section 5.2.5. The stepwise approach to the teaching of science investigation employed by T2 also relates to the strong process orientation to science teaching she displayed throughout this unit and is discussed in Section 5.2.7.

Since the focused teaching of individual steps was always situated within a wider authentic context or investigation (see Appendix K), T2's approach seems best viewed as sociocultural with the stepwise approach seen as the staged introduction to authentic practice characteristic of apprenticeship situations. The characteristics of T2's sociocultural practice are described next.

5.2.1.2 Sociocultural approaches

Sociocultural approaches were analysed as described in Section 3.6. A typical lesson analysis is provided in Appendix L. Two major features were the extensive use of authentic activities, which afforded students multiple opportunities for enculturation into science-specific vocabulary, text, and practices, and staged tasks, which were managed through highly structured direct interactions. Other key features were the absence of a sense of joint enterprise and the nature of the socially mediated action and distributed cognition in this classroom community. These features are discussed in the above order.

T2 engaged the students in fair testing, a form of scientific investigation, with specific foci on developing testable questions derived from an issue of concern or interest, developing a scientifically reasoned hypothesis, identifying and controlling variables, presenting data in an orderly manner, and writing evaluative and related

conclusions. These practices reflect aspects of scientific endeavour. Students also evaluated their own and others' reporting of their investigations, another component characteristic of scientists' work.

Engagement in authentic activities enabled acts of enculturation, with opportunities to develop scientific vocabulary including "hypothesis", "controlled variables" and "independent variables". Investigations used in class related to students' common experiences, establishing instructional congruence, another sociocultural enculturation practice. An example is the way T2 introduced the identification and control of variables as part of a group investigation into the absorption of milk by cereal:

T2: Who has weetbix for breakfast?...Does anyone break their weetbix up and then put it in the bowl and then pour their milk in, or hot milk? Or we might add different types of sugar. All of these things that we are doing could affect the rate at which milk is absorbed by the weetbix. What about some of the other things that may affect the rate or speed of which it is absorbed?

S1: How many weetbix we use...

S2: The type of milk ...[discussion continues in similar manner]

T2: Now all of those different things mentioned we call them something special in science, does anyone know what we call those things?

S7: Variables

T2: We do call them variables, you're on to it! So all those things are different things that we can change or which might affect our absorption rate, we call those variables. (LT/1/5)

Students worked in groups to list possible variables and conferred with other groups' lists. This provided an opportunity to make another aspect of scientific endeavour explicit: scientists build on and use each other's ideas and methods.

Just have a quick scan for anything that you haven't got...Now in science it is perfectly ok to go around and borrow ideas because when we are setting up fair tests it is important that we have considered or thought about all of the possibilities. (T2/ LT/1/5)

T2 provided frequent examples of expert practice, sometimes through modelling, as with the provision of a completed investigation planning sheet and her demonstration of the use of a pipette. Most common was the provision of specific success criteria, a characteristic of her teaching as described in Section 5.1.6. (p. 103). Occasionally T2 highlighted a student's response as an example of scientific practice.

The fair testing process was introduced in a series of staged tasks. Each step of the process was highlighted during a sequence of class investigations (Appendix K). T2

structured students' direct interaction with a particular step using several activities. For instance in teaching about hypotheses, students first worked in groups to examine scientific information T2 provided on rates of reactions and the chemical composition of milk. Each group then developed a reasoned hypothesis as part of their planning for the first class practical investigation on absorption of milk by cereal. This was followed by an activity where students worked in pairs to order a given set of hypotheses according to their quality. Pairs then justified their ideas during teacher led class discussion:

T1: Put your hand up if you can tell me what you think is the least good example of a hypothesis. [Name], what do you think it is?

S1: The one that says "I think the little pieces will dissolve first."

T2: You're absolutely right. Why is that the least perfect hypothesis, what was your reasoning?

S1: Cos it doesn't say why.

T2: OK. It doesn't have the word that we're looking for, which was?

S2: Because.

T2: Because. That's the only one of the six that does not have the 'because' statement and remember from this morning, that was critical. Wasn't it? I said every hypothesis that you write in your whole life time needs to have a 'because' statement. (LT/3/5)

Students returned to their groups to improve their hypotheses about absorption of milk using success criteria provided by T2. The steps of identifying and controlling variables and developing a testable question were treated similarly.

T2 used such structuring of direct interaction continually. Other forms of guided participation such as mutual bridging of meanings and structuring using narrative or routines were used infrequently.

While T2 included many strategies associated with participation in communities of practice, the establishment of a sense of joint enterprise was not evident. While there were moderate to high levels of student engagement, measured by proportion of on-task behaviour, this appeared more an act of compliance than interest or passion. When asked how much they liked the unit, most students responded by selecting "some of it was ok" rather than using the more positive options, although most suggested their teacher was very effective in teaching it.

Students had few opportunities to contribute to class understanding of the nature of fair testing. Teacher direction without co-construction was common, for example when revisiting the development of testable questions:

They [referring to worksheet] have picked one of the causes and have written up a question that could be investigated. What they have come up with is "Does the amount of nicotine in a cigarette affect the colour of the teeth?" Now that is not something that practically you could investigate from the resources that we have at school; however, it is a question that can be scientifically investigated, if you had the right sort of set-up. (T2/LT/18/3)

Authoritative dialogue, both interactive and non-interactive, was predominant. The nature of classroom discourse is discussed in Section 5.2.1.4.

Analysis of transcripts revealed only one example of active meaning making by a student in dialogue with T2. Other examples may have occurred in group interactions that were not observed or recorded. T2 roved constantly during group tasks checking on groups and individuals. Noise levels meant these conversations were rarely captured in recordings.

Students more often practised prescribed processes than were given opportunity to describe or define them for themselves. Their own investigations were to show they had mastered the processes and could apply them in a new situation. The individual nature of the required science fair exhibit and the competitive nature of the science fair may have contributed to the lack of a sense of joint enterprise.

The final point for discussion in this section is the nature of socially mediated action and its connection with distributed cognition. Analysis of socially mediated action indicates that there was much opportunity for both individual and participatory knowledge construction, with some opportunity for cultural scaffolding. Individual socially mediated learning opportunities were mainly of three types: teacher explanation, engagement in an individual practice activity designed by T2, or feedback by T2 verbally to the class or groups, or through marking or conferencing.

Comparing patterns of socially mediated action with those of distributed cognition shows that, as would be expected, the times when students were available to each other and the availability of symbolic tools are matched by opportunities for participatory and culturally mediated knowledge construction, respectively. Little access in class was provided to technological tools. The symbolic tools accessed were, with one exception, material developed by T2, such as success criteria and a completed investigation planning form. The exception was information provided on the packet of the cereal. Students therefore had little access to examples of scientific practice other than that provided by T2. While they were encouraged to locate scientific information related to their topic, this was not shared until science fair exhibits were displayed. Student work was rarely shared during observed

lessons. This may have occurred more often during unobserved lessons led by the student teacher later in the unit, as more individual work was being developed at that time. In observed lessons cognition was narrowly distributed across T2 and her students with little source other than T2. This placed heavy dependency on T2's content knowledge, in particular her syntactic knowledge as this was the focus of the unit.

To summarise this section, T2 used a range of sociocultural strategies. While much use was made of authentic and staged tasks together with structuring of direct interaction, a sense of joint enterprise was absent. The limited nature of distributed cognition meant that the opportunities for individual, participatory and culturally mediated learning were dependent largely on T2's knowledge base.

5.2.1.3 Classroom management and organisation

Figure 5.2 shows the frequency of use by T2 of components of this knowledge. The major features of this analysis are presented and discussed below.

Figure 5.2: Frequency of observed use of knowledge of classroom management and organisation by T2

The setting of clear expectations featured significantly in T2's practice and has been described previously. Provision of feedback was another predominant feature. Feedback was directed to individuals, groups or the whole class, and framed to further clarify expectations, for example:

Now, some of those questions that were given to me were actually not scientific questions. They're not ones that we can test. They're ones that we can go away, do a bit of research and answer the question without actually testing anything physically, OK. Now, the purpose of doing a science fair investigation project is for you to do some science, to actually carry out a scientific test to find an answer to something. (T2/LT/15/5)

Positive feedback also emphasised her expectations:

I was really pleased to see that so many of you identified that Number Six was the best hypothesis. And you were able to work out it was good because it talked about surface area and it was good because it talked about dissolving rates. (T2/LT/3/5)

Monitoring student performance was the other common feature. This was managed in three ways: through regularly marking student work, teacher led class discussion, and through observation and discussion with individuals and groups. The nature of class discussion, although interactive, was often authoritative, a feature discussed in the next section. Monitoring student performance informed next teaching sessions.

The frequency of 'managing groups' reflects T2's high use of group work for practice of process steps. Structuring of new information was replaced in the main by the overall staged approach used to teach the fair testing process and through setting expectations for specific tasks. Periodically T2 reviewed what had been covered and what was still to be done, thus providing a structured overview.

T2 anticipated possible problems, noticing off-task behaviour early and resettling students. Students were quickly refocused following interruptions, most commonly for school notices. T2's knowledge of classroom management meant most of the lesson time was spent on science learning.

5.2.1.4 Classroom communication and discourse

The patterns of dialogue in Class 2 reflected T2's directed approach. The observed lessons contained two to four periods of teacher talk ranging from one to five minutes in duration. This discourse was authoritative and non-interactive and most commonly used to explain or model a task and set expectations:

Now if you have chosen the type of milk then underneath where it says in your box, "What is my new question?" and using another stick it note, I want you to rewrite the question. If you have chosen the type of milk, your

question would read something like “Does the type of milk affect the rate at which milk is absorbed by the Weetbix?”... If you have chosen not to use milk at all and have chosen different types of liquid: “Does the type of liquid affect the rate of which it is absorbed by Weetbix?” So using a new stick it note, I want you to write a new question and put it in the box, which is second from the bottom. (T2/LT/1/5)

Another use for this form of discourse was review and class feedback, often at the close of a lesson:

Okay you have worked very hard today, I do appreciate it, it's Friday afternoon. We are getting there, we need a little bit more work on how we make questions, scientific questions, because we are still at the point where we are writing good questions but they are research questions, they are not things that we can scientifically test but we will get there. (T2/LT/18/5)

Teacher led class discussion, while interactive, included both authoritative and dialogic forms. T2 often used the question-response-evaluation pattern characteristic of authoritative interactive dialogue to check student understanding:

T2: So which is our independent variable? [Name 1]?

S1: The one thing that you're going to change.

T2: The one thing that you're going to change. The one thing that you're going to test. Everything else gets put under the what variable? The something variable... [Name 2]?

S2: It starts with 'c'.

T2: Absolutely right.

S2: Um, control.

T2: Thank you. Control. OK! (LT/3/5)

Class discussion was a time when students' ideas appeared to be elicited in order to monitor their acquisition and accuracy. Such discussion could be seen to serve a dual purpose: hearing a student's response and the teacher's evaluation was an opportunity for other students to learn and for informing the teacher about competence levels.

Dialogic interactive teacher led class discussion was predominant in reporting back from group and individual tasks. This too provided opportunity for formative assessment as well as sharing ideas. This discourse type was also observed as T2 interacted with groups and individuals during independent tasks, although the interactive authoritative form was also used in these situations.

To summarise and conclude this section, T2 used her general pedagogical knowledge to support her staged approach to teaching fair testing. Use of non-interactive authoritative discourse facilitated the setting of clear expectations for

each stage. Use of structured group and independent tasks provided multiple opportunities for students to engage in, and practise, each step. Use of interactive discourse, along with marking and observation, assisted with monitoring student performance. Both non-interactive and interactive authoritative discourse provided opportunities for students to identify and improve their competence with fair testing steps.

T2's approach to teaching science appeared to be her normal teaching approach and not an approach employed specifically for science. Students appeared accustomed to group work and class discussion. Written success criteria for incremental steps were observed displayed in the classroom for English. Interviews with focus students confirmed that use of success criteria was common practice in their class.

5.2.2 General aims, purposes and values of education and assessment

T2's educational aim for science was to prepare her students for secondary school and to raise awareness of science as a possible career.

In terms of going to college they need to know that they have already done science so it's not something completely new to them...it's such a huge opportunity in terms of career and job prospects and it's a need in New Zealand as well for kids to move into that area. (T2/I/18/5)

She believed learning about fair testing would support students' secondary science learning:

Fair testing is a big thing and we feel quite strongly that's how we can best prepare our kids for college. If they have a good understanding about what fair testing is...I mean it's so huge...my understanding of it is that it sort of underpins a lot of investigations that they're going to do in the future. (T2/I/18/5)

She felt the fair testing unit helped develop students' critical thinking:

It takes them from not thinking about the world around them to actually critically thinking about the world around them. I think that that's probably our biggest thing in terms of what we're trying to achieve in science here. (T2/I/18/5)

This belief in the importance of fair testing helps explain T2's emphasis in building students' competence with this process. The goal was larger than producing an exhibit for the science fair; she saw it as enabling students' future science learning and critical thinking.

T2 used assessment for several purposes. Firstly she used a range of formal and informal assessment strategies to monitor student competency with the different steps. Strategies used included a pre and post-test on terms associated with fair testing, observation of group work, teacher led class discussion, frequent marking and individual conferencing. This monitoring informed next teaching. T2 often changed what had been planned in response to formative assessment:

T2 had been marking Sunday night and as a result completely changed what she had intended to do: felt the need to support development of investigable questions more, so developed criteria and new list of questions and planned an extra lesson as well as made time for conferencing with students before the next planned step in the afternoon. (FN/21/5)

T2 used assessment to inform the feedback that was a feature of her teaching. Her use of success criteria and conferencing showed understanding of another purpose for assessment, to help students identify ways to improve their own work: “I think the most powerful bit was the conferencing one to one. Right, where is your question? Okay, does it meet the criteria? How could you change it to meet the criteria?” (T2/I/28/6). She worked with students to develop the skills needed for evaluating and giving peer feedback on each other’s projects: “...the assessment sheet you have is quite detailed...you will need to read the information on the board carefully to make a judgement...Why would you tick the ‘no evidence’ box?” (T2/LT/21/6).

T2’s aim for her science education programme was to prepare her students well for secondary school and to become critical thinkers. She believed competency with fair testing contributed to these goals, and her knowledge of the purposes of assessment was deployed to this end. Knowledge of fair testing and its significance in science relates to syntactic aspects of T2’s science content knowledge and beliefs, and is discussed further in Section 5.2.5.

5.2.3 Learning and learners

T2’s stated views about learning and learners were generally consistent with observations of her practice, although there were anomalies.

T2 believed, and demonstrated in her practice (Figure 5.1), that it was important to provide a balance of group work and whole class sessions in order to cater for the ways different students engage and contribute to discussion:

In a group of thirty there are going to be kids that don’t switch in and don’t think. That’s why I try and have a balance of whole class because some of them need the support of the other kids in the class that are a bit more switched on and onto it. Some of them have got that knowledge but they don’t want to share it because they’re too shy in a whole class situation, but

put them in a group situation and they're more likely to talk and discuss ideas – so that's why I try and have a balance of the two, because some kids need one, some the other, some kids need both. (T2/I/28/6)

Students were given opportunities to first develop or share ideas in a group before they were aired with the class.

T2 believed students learn by doing practical work, which she regarded as motivating: "If you can get them investigating and doing something practical then they learn – they're more motivated. I see it [practical work] as very important because of that engaging and motivating [factor]... (T2/I/18/5). While she regarded practical work as motivational, less class time was spent on it than aspects such as developing testable questions and hypotheses.

In reviewing the unit, T2 identified modelling and scaffolding as the most significant aspect of her science teaching practice:

I just think all that modelling right the way through using the templates and the criteria sheets, all of that, that modelling, that constant doing as a class, doing as a group and then doing independently, that scaffolding. (T2/I/28/5)

Bookwork served as part of the modelling process:

I try to give them what they need to support their independent work. So if they are required to do something independently, I like them to have something in their book that they can refer to, so they've got something concrete that they can then look back on, or see a good model of what they're expected to do without me. (T2/I/18/5)

In this way T2's expectations were extended into independent work. T2 ensured students' work was sequenced and in order, for example:

There is a reason why I didn't get you to stick that [sheet] in this morning because it's going to go after this. So, this is the learning intention...this goes on to the top of your page underneath the date. Then this gets stuck in, please. (T2/LT/3/5)

Time spent working with individuals was seen by T2 as important for learning too:

One-to-one discussion: roaming around the room this afternoon saying to them, well, what you've written there is a research question, what's your independent variable there? I haven't got one. OK, so how could we change that question so that it's something that we could test? Again, it's that one-to-one, because you've got them there and they're only concentrating on you and not whatever else is going on. (T2/I/28/6)

The value of engaging with individuals appears to be for the monitoring and teaching opportunity it provided.

Few beliefs about the nature of student characteristics with regards to learning were expressed. One conversation between the researcher and T2 provided some insight:

“I sometimes expect too much of them and push them too hard, you forget that they’re like they are...” T2 went on to describe [Year 7 and 8] students as disorganised, busy, and self-focused, in a way that conveyed compassion and fondness. (FN/15/5)

This view may explain why she ensured students’ work was organised.

An emphasis on monitoring, teacher modelling and scaffolding in both belief and practice fits with a view of learning where the teacher is seen as the provider and overseer of knowledge development. T2’s beliefs about the disorganised nature of Year 7 and 8 students may have contributed to this view. Although T2 espoused a belief in the importance for learning of discussion, class discussions were used more for informal assessment than co-construction.

5.2.4 Educational context

T2’s knowledge and beliefs about the educational context identified in the implementation of this unit concerned the school community and knowledge of the students in her class. Knowledge of the New Zealand community, in particular its bicultural heritage, was not evident.

T2’s knowledge and beliefs about the school community that supported science centred on staff needs, school organisation and parental involvement. T2 believed her role was to support staff firstly by planning science: “It was myself and one other teacher that did a lot of the planning. We’ve done the planning for the last four years for the school. And we organise all the resources as well” (T2/I/18/5). Providing and organising the resources was a way of supporting teachers who, she felt, generally lacked confidence in teaching science:

When I came into the role of science curriculum leader a lot of teachers were apprehensive about teaching science and a lot of the organisation actually put people off teaching science. So we decided that we would make that as easy on people as possible. So a lot of equipment was organised and purchased en masse and then divided up for classes. We have a booking system where teachers book equipment and it gets delivered to them and they just have to bring it back. (T2/I/18/5)

Scientific equipment, including spirit burners and pipettes, was well organised when used by Class 2. T2 purchased consumable items for use in science lessons: her

knowledge of school budgeting and resource management systems supported the implementation of the unit.

T2's knowledge of school organisation and the nature of the staff meant she planned and led staff meetings to support less experienced teachers:

We've got a couple of provisionally registered [first year] teachers, three or four year teachers and this is either their first or second time through the process....We had a professional development staff meeting which was done right at the beginning of the term. (T2/I/14/6)

Her knowledge of school organisation also allowed her to facilitate school and syndicate-wide planning that enabled connections to be made with other learning areas beneficial for science. As an example, the whole school had covered procedural writing in the previous term to prepare students for describing methods appropriately for reports on investigations for the science fair.

T2's knowledge of parents meant she saw them as both a help and a hindrance to student achievement in completing their science fair investigations. That many parents provided guidance and support for their child was useful:

For some of them [students] I think the whole level of independence that something like this requires is just too much for them. I think that they need a lot of guidance and for some they haven't had that support from parents sometimes. (T2/I/28/6)

However, she also knew from previous experience that parental intervention could confuse students and therefore organised the production of science fair displays in a way that supported both students and parents:

Now, I'm going to give you, and this is really for your parents' information as much as yours, a letter informing your parents about the science fair and why it is that we're doing all this work in class. (T2/LT/15/5)

We set it up in a way that the majority of the students actually assemble their board at school because we find that although we publish the guidelines mum and dad at home say "Oh no it looks much better if that goes over there!" and then of course the kids come to school and the teachers say "Oh no it needs to be in this place. You can't have your conclusion before you display your results!" and then we end up with upset kids. So what we say to them is do everything at home and get to the point of putting it on your board and we'll give you time in class to do that and that's worked quite well. We've done that for the last few times. (T2/I/14/6)

T2's knowledge of parents meant she informed them early about expectations to maximise their support but organised proceedings so she had final oversight of the end product.

T2 drew on knowledge of her students in using familiar contexts such as absorption rates of cereals, although this also linked to her PCK as this context had been used to introduce fair testing in previous science fair units. She also utilised her knowledge of the particular nature of Class 2:

They do need a lot of scaffolding and a lot of support...I've got quite a low group. They can't pick up instructions as well as other kids, and then there's a small group of them, we've got kids with dyslexia-there's range of [special needs]...and then I've got a couple at the top. As a general group they are a little bit towards the lower end. So I try and keep activities reasonably short, sharp and active. A lot of discussion. (T2/I/18/5)

She used knowledge of individual students when managing the class: "You two can work together. [Name] will have you under her thumb!...Now listen, 'cause there's quite a few instructions coming up and I know how some of you have trouble with those. (T2/LT/3/5).

T2's monitoring during group tasks meant she could nominate students who could give examples that illustrated what she required: "[S1], your group picked a good one: why was it that those things were identified as showing as part of the diagram?" (T2/LT/1/5). Monitoring student work also meant she could identify and support struggling students. For example, T2 prepared a sheet of testable questions reflecting student interests for those students she knew had not developed them in time. Awareness of students' needs also gave her an appreciation for depth of individual achievement:

...the kids that have done very well for them...[Name], he looked at the alkaline and the acid in the soil and he had his plant box there...and you know he's someone that struggles and yet he captured something that was interesting to him. (T2/I/28/6)

In summary, T2's knowledge of the school community enabled her to support teachers in the school during this science unit, access appropriate equipment and facilitate parent support in a way that did not confuse students. Her knowledge of the class and individual students facilitated her effective management of the class during science. T2's knowledge of individuals, informed by close monitoring, enabled her to support specific needs and enhanced her appreciation of individual achievement. T2's syntactic science content knowledge was influential on and through her use of contextual knowledge. Her knowledge and beliefs about fair testing influenced the support provided for other teachers and the content of newsletters to parents. The nature of T2's syntactic science content knowledge is discussed in the next section.

5.2.5 Science content knowledge

The science fair unit focused largely on the processes of scientific investigation. In the framework of teacher knowledge used for this thesis, knowledge of these processes forms part of syntactic knowledge: understanding the means by which ideas are developed and become accepted within the discipline (Schwab, 1964; Shulman, 1987). T2 displayed considerable depth of syntactic science content knowledge in implementing this unit but with limitations. Substantive knowledge relevant to the contexts of class investigations was demonstrated.

5.2.5.1 Syntactic knowledge and beliefs

T2's science syntactic knowledge included that science investigation involves empirical testing and observation of the natural world: "the idea is to get questions that could be investigated scientifically by *doing* something" (T2/LT/15/5). She also saw collegiality as part of scientific endeavour: "Now in science it is perfectly okay to go around and borrow ideas... because it's important that we have considered or thought about all the possibilities..." (T2/LT/1/5). T2 believed that useful scientific investigations develop from curiosity and wondering about the world: "...we start from the wonderings, the reasons why this might come about (T2/LT/18/5); "Some of them really got excited about their topics. They clicked into that wondering...but [some] didn't grasp that whole idea of coming from their own curiosity" (T2/I/28/6). She also recognised that science involves critical consideration of claims:

One of the members of the group was prodding the weat-bix with a pipette and the other member of the group said 'You can't do that! Because that's affecting the results...' and I thought then, that's science: that they're actually challenging each other. (T2/I/18/5)

Such debate was not a focus in lessons, although T2 facilitated summative peer assessment of student science fair exhibits.

As evidenced in the science fair judging criteria she provided for students, T2 recognised that scientific hypotheses are reasoned, cognisant of current scientific thinking and able to be tested, observations measured and recorded accurately in an organised manner, and that reflection on validity of results is important. The success criteria she gave to students showed that T2 believed that scientific reports of investigations relate the results to the hypothesis, provide an explanation for the results, identify any patterns, trends or anomalies in results, and identify areas for further research (FN/21/6). From observations it was clear that T2 understood that fair testing involves selection of an independent variable to change in a measured

way, then monitoring the effects of that change on the dependant variable whilst controlling other variables (Appendix K).

An aspect of syntactic knowledge which may have limited learning opportunities was T2's belief about the importance of fair testing to science investigation. Her knowledge of other forms of investigation, for example exploration and pattern seeking, was not apparent.

In her learning in the classroom [Name]'s showing evidence of knowing what a fair test is, yet that transfer to what she's doing – she's got so hooked on this experiment that she really wants to do – but she can't make the connection between that and fair testing. (T2/I/14/6)

T2 did not believe other forms of scientific investigation to be acceptable for the science fair. This belief may have resulted from T2's experience of past science fairs or from her curriculum knowledge, discussed in Section 5.2.6. The development of T2's content knowledge is discussed in Section 5.3.

5.2.5.2 Substantive knowledge and beliefs

The focus on fair testing meant that in comparison with syntactic knowledge, T2 exhibited relatively little substantive knowledge in this unit. She demonstrated knowledge of particle theory, factors that influence rates of reaction and topic specific knowledge concerning the properties and composition of milk. The latter were listed in an information sheet she developed for students to help them produce scientifically reasoned hypotheses. Comments during the lesson confirmed T2's understanding:

The more surfaces mean?...More collisions. Right. The milk molecules charging around are more likely to bump into the weet-bix molecules 'cause there's more of them exposed and the reaction will happen a lot quicker. (T2/LT/3/5)

5.2.6 Curriculum knowledge

T2 did not plan this unit formally so did not make explicit connection to the then current curriculum (MOE, 1993a). However, when discussing planning she used terminology common in this document such as "material strand," "chemical and physical change," "forces and motion" (T2/I/18/5). T2's beliefs concerning the importance of fair testing have been highlighted in previous sections and may have derived from her curriculum knowledge. The 1993 document focuses largely on fair testing in connection with science investigation. Year 8 students, as in Class 2, usually work at Level 3 or 4. The Nature of Science and its Relationship to Technology Strand for Level 3 states that students can "recognise when simple

investigations can be classified as a 'fair test' and make decisions about the worth of results" (MOE, 1993a, p. 31). For Level 4, the equivalent objective is that students can "plan and carry out a 'fair test' and make decisions about whether the conclusions drawn from an investigation are soundly based" (MOE, 1993a, p. 32). Furthermore, the Developing Scientific Skills and Attitude Strand states that at Levels 3 and 4 students can "design 'fair tests', trials, and surveys with an attempt to control for obvious variables" (MOE, 1993a, p. 44). Examples largely pertain to fair testing and no other forms of investigation are emphasised. T2's focus on fair testing therefore was justified in terms of the curriculum achievement objectives relevant to her class and reflected accurate curriculum knowledge of the specific science curriculum documentation pertaining to her class level.

Other aspects of T2's syntactic knowledge also resonated strongly with curriculum knowledge. The Developing Scientific Skills and Attitude Strand achievement objectives include that at Levels 3 and 4 students can: "ask questions of themselves, their group, and resource people and identify questions suitable for scientific investigation" and "use their science ideas and personal observations, and those of others, to make testable predictions or to identify possible solutions for trialling" (MOE 1993a, p. 44). These expectations relate closely to knowledge exhibited by T2 pertaining to hypotheses and the nature of questions guiding scientific investigation, suggesting that syntactic knowledge may have developed in these areas as a result of curriculum knowledge. The development of T2's content knowledge is discussed further in Section 5.3.

T2's belief, described in Section 5.2.2 (p. 114), that fair testing underpinned science investigation at secondary school level reflects her vertical curriculum knowledge. The Developing Scientific Skills and Attitude Level 5 and 6 achievement objective states that students can "design 'fair tests', simple experiments, trials, and surveys, with clear specification and control of likely variables" and at Levels 7 and 8 "design systematic tests, experiments, trials, and surveys with rigorous identification and control of variables" (MOE, 1993a, p. 44). T2's beliefs relate strongly to these objectives.

Observations revealed T2's broad knowledge of horizontal curriculum and its application to this science unit. The selection of health issues as a source of scientific questions demonstrated knowledge of current topics in other curriculum areas. T2 was aware of students' literacy needs whilst teaching science: "When you're conferencing there's the science that you're conferencing but then there's

also all the other stuff. You know some of the kids actually can't write paragraphs so there's all that happening in the conferencing as well" (T2/I/14/6). She also planned and taught concurrently units in writing and mathematics to support students with science: "We are doing explanations at the moment, and statistics because we're expecting the kids to use the graphs to support or to display their results, so we teach that" (T2/I/18/5). Knowledge of horizontal curriculum was also used in preparation for the science unit: "...deliberately last term we all covered procedural texts so that they had those skills for when they were writing methods" (T2/I/14/5).

T2's knowledge of resources included the *Making Better Sense* series. In addition to supporting teachers with science content and activities, these books provide planning formats for student investigations that focus on fair testing processes (e.g., MOE, 2001, p.16). Other forms of investigation are not supported. T2 described other Ministry provided resources she had used for science, including the *Building Science Concepts* series, *Connected* and ARBs. She used student focused science magazines as part of her reading programme. T2 provided and demonstrated appropriate use of a variety of scientific equipment for her students during the observed practical lesson, including test-tubes, test-tube racks and holders, plastic pipettes, and spirit burners.

T2 drew on a range of curriculum knowledge during this unit. Horizontal curriculum knowledge was used to support students' science reporting, and knowledge of scientific equipment was used in demonstrating scientific practices. The strong focus on fair testing reflected that of the curriculum, suggesting curriculum knowledge as a possible source of syntactic knowledge.

5.2.7 Science pedagogical content knowledge

T2 used a number of categories of PCK in implementing this unit, including knowledge of science instructional strategies, syntactic strategies, knowledge of how and what to assess in science and knowledge of student difficulties, all of which were applied to a process orientation to science teaching.

Teaching the steps of a fair test investigation is characteristic of a process orientation to the teaching of science (Magnusson et al., 1999). This orientation could be considered appropriate in preparing students for a competition in which their ability to investigate scientifically was to be examined. Teaching science process without context was the result of a review amongst staff prior to the unit:

...through the review process that we did, that was a very strong outcome: that it was too much and that we felt that we weren't doing either [context or process] well, so let's just focus in on this [process], and we'll deal with the content later. (T2/I/18/5)

T2 was ambivalent about this decision: "...it's difficult to try and grasp the idea of questions [without a context]. It's been quite difficult trying to give them enough to go with it...this is abstract" (T2/I/15/5). She reflected that grounding scientific processes more strongly within a context, as she had done previously, was more effective: "I don't think that you can just keep teaching process, I think you need content to support that" (T2/I/18/5). T2's reflection was a process through which she modified and developed her PCK as will be discussed in Section 5.3.

T2's knowledge of instructional strategies for science observed in this unit included one instance of a scientific explanation used to convey substantive knowledge. This was an explanation of reaction rates in which molecules were described as whizzing around and bumping into each other, which fits with Treagust's (2007) categorisation of 'putting meaning into matter'.

As will be described in Section 5.4, T2's students' perceptions of their learning included developing reasoned hypotheses and control of variables. This learning contributes to understanding the nature of scientific knowledge and how it is established. Methods T2 employed in teaching these aspects were therefore categorised as syntactic strategies, as defined by Smith (1999). Scientific syntactic strategies included demonstration and use of activities that work (Appleton, 2002).

T2 demonstrated each step of the practical investigation of sugar levels in crackers before students performed the experiment for themselves. These demonstrations included safe handling of spirit burners, labelling of samples and measuring liquid using plastic pipettes. In other lessons, T2 provided a completed example of a fair testing planning format and modelled development of a testable question. These are all demonstrations of scientific processes. T2's use of activities that work involved experiences that she had used successfully with classes in previous years, for example the milk and cereal investigation to teach about variables and the use of planning boards to help students design investigations. These activities had been passed on to her originally from her mentoring teacher. They had become part of her existing syntactic PCK for this topic as she selected and used them specifically for syntactic teaching.

Other strategies T2 employed to teach syntactic knowledge were from her general pedagogical knowledge. They were not specific to science when used initially, although they may have helped to build science PCK as will be discussed in Section 5.3. Syntactic understandings were made explicit in success criteria, use of which was normal teaching practice for T2 as described in Section 5.2.1.4. She was observed applying strategies from the school's thinking skills programme in teaching syntactic knowledge: students were asked to use a set of generic question keys to generate a range of scientific questions (LT/15/5).

T2's knowledge of how and what to assess in science fitted with her staged approach and relied on her syntactic knowledge. She closely monitored students' achievement of each stage using a variety of methods, looking for the aspects of syntactic knowledge made clear in success criteria: "I mark as much as I can. A lot of it is discussions with kids. A lot of it is observing in their group work and posing a question to the class and getting blank looks back" (T2/I/28/6). This knowledge of how to assess does not appear specific to science. What made assessment science-specific was what she looked for, her syntactic knowledge: "In my conversations with them I'm talking about variables, I'm talking about the way they structured their method..." (T2/I/14/6). Summative assessment of science fair projects by T2 included a set of formal criteria used school wide, developed by her based on the judging criteria provided by organisers of the regional science fair.

T2's knowledge of student difficulties meant she recognised potential and real difficulties students encountered and could support these. She knew that students often struggled to develop a relevant, testable question, explaining why this formed a particular focus during the unit:

That's probably our biggest challenge: to transfer some of their wonderings into actual questions that they can test....Kids do find this hard and it is hard to teach as well. I think that the best way to get kids to come up with questions is to work one-to-one. (T2/I/18/5)

This aspect of PCK appears to have developed through reflection on past experiences. Other aspects of PCK described above appear to have developed from combining general pedagogical knowledge with syntactic knowledge. Development of T2's knowledge is discussed further in Section 5.3. A summary of the teacher knowledge evident in the unit is first presented.

5.2.8 Summary of teacher knowledges evident in the unit

T2 demonstrated aspects of each of the knowledge domains. Her process orientation meant that the syntactic knowledge T2 demonstrated was a significant influence on the nature of learning opportunities provided. Whilst it enabled provision of a range of experiences relating to fair testing, it limited learning opportunities to this form of investigation. Her beliefs concerning the significance of fair testing reflected the emphasis in the then current curriculum document, suggesting that curriculum knowledge may have impacted on the development of syntactic knowledge. T2's general pedagogical knowledge was used in teaching syntactic science aspects. The development of T2's knowledge is the focus of the next section.

5.3 Development of teacher knowledge

While T2's general pedagogical knowledge contributed much to the provision of learning opportunities, the development of T2's science content and pedagogical content knowledge are of most interest as they most strongly influenced the nature of learning opportunities.

Reading and the internet informed T2's substantive science knowledge. Her knowledge of resources was helpful:

I do a lot of reading in terms of up-skilling myself so that I know what it is that I'm talking about before I'm doing a content unit... I go to the library and get out books, I use the *Building Science Concepts* (BSC) books, they're great, I like those. I like the layout of them, I like the fact that they go from the big ideas, and then they draw out, I really like that. (T2/I/18/5)

The BSC resources (e.g., MOE, 2002) along with the *Making Better Sense* series (e.g., MOE, 2001) were valued because they made important scientific ideas explicit as well as providing detailed topic specific knowledge, indicating that T2 found both knowledge types helpful.

T2 suggested her syntactic knowledge developed from mentoring provided by an experienced science teacher, opportunities for discussion with local science fair judges, and studying high achieving exhibits:

The other teacher that I've worked very closely with is science experienced – so I think I've learned from her, that's been my professional development...I get the opportunity to talk to judges who come and do the science fair...I go to the regional fair and I see the good examples, and I read all of those. I see good examples so then I think that helps me to teach. (T2/I/18/5)

Perhaps familiarity with the product rather than the process influenced the emphasis in her syntactic knowledge; aspects that were easily seen in such investigation reports were emphasised over less visible science practices such as debate and critique.

Repetition and validity were not emphasised during observed lessons. T2 received feedback from judges concerning this aspect: "I agree with what the judges said. Validating results, repeating the fair test: that was something that I probably should have done" (T2/I/28/6). This feedback informed her syntactic knowledge.

The criteria provided by the science fair organisers informed the development of success criteria, a manifestation of her syntactic knowledge: "Criteria have been developed and guided by the regional science fair guidelines" (T2/I/14/6). The judging criteria provided by the regional fair organisers do not specifically limit investigation to fair testing:

The exhibit demonstrates clear scientific thought, the application of appropriate scientific methods, an appreciation of the need for accuracy in observation, measurement, data collection and reporting; and an understanding of the underlying or related scientific principles embraced within the project. (<http://www.sciencefair.org.nz/~science/?q=node/4>, downloaded 26th July, 2010)

However, their 'hints for success' strongly suggest use of fair testing principles:

Plan your experiments or your design. Try to be methodical, logical and organized! You have identified one variable you want to investigate, but are there others? For example, I am investigating how much baking powder I should put in my cake mixture to make the cake rise the most. But what other variables might affect the way cakes rise? Other ingredients in the recipe? Cooking time? . . . All these other variables must be kept the same throughout my experiments if it's the amount of baking powder I want to check. (<http://www.sciencefair.org.nz/?q=node/17>, downloaded 26th July, 2010)

The school criteria heavily emphasised the need for a fair test:

Investigation question can be tested or experimented through a fair test... Design, record and use a Fair Test with an understanding of the relevant scientific concepts... All variables are clearly identified and controlled during the fair test....Fair tests are repeated or other tests carried out to validate results. (School science fair judging criteria/ FN/22/6)

Fair testing was specified in the school criteria, perhaps as a result of curriculum knowledge as described in Section 5.2.6. Information provided by science fair organisers could have reinforced beliefs about the significance of fair testing.

T2 identified and adopted many valuable aspects of syntactic knowledge from reifications of practice including successful exhibits, judging criteria and, perhaps, the

curriculum. T2's lack of knowledge about the diversity of scientific forms of investigation highlights the difficulty for teachers in attempting to develop such knowledge.

With regard to development of PCK, cognisance of the difficulties students commonly displayed was attributed to experience: "Just learning with the kids and learning the process with them and what their challenges have been" (T2/I/18/6). The value of reiterating units of work with different groups of students was therefore evident.

In teaching components of her syntactic knowledge such as the nature of a scientific hypothesis, T2 appeared to draw on her general pedagogical practice: "What you've seen [using success criteria] is what I would do in any curriculum area" (T2/I/18/5). The development of explicit learning intentions and success criteria with students, and their use by students in evaluating their own and others' work is a feature of the Assessment to Learn (AToL) professional development project instigated by the MOE (Poskitt & Taylor, 2008). Their use has been reinforced in the numeracy and literacy initiatives and is common in primary teacher practice in New Zealand.

T2 applied pedagogies from other school-wide professional development opportunities to her teaching of science, for example:

The last unit that I planned, I actually planned a series of lessons that fitted in with the multiple intelligences...that was quite exciting. It was the first time that I'd planned in that way. It just sat alongside, it didn't replace, and it didn't take over what I would normally have done, it was just a different way of thinking about planning for science. That worked quite nicely. It provided a greater range of activities. (T2/I/18/5)

A similar example occurred in the observed unit when she used worksheets developed from professional development in thinking skills:

Those particular ones that I used today have come from our teacher in charge of giving us professional development in terms of thinking they're new to me. Now that I've used them, I'll probably make some changes myself, given that there are some bits of them that haven't worked particularly well – but until you try these things it's hard to know just how well they're going to work. (T2/I/18/5)

The comments above suggest that reflection on application of new strategies to science was regular practice for T2. Reflection was also seen during a lesson using question keys, another strategy from the thinking skills programme that T2 tried in conjunction with syntactic knowledge: "Right, in my head, that stage of the lesson went a lot better than in reality" (T2/LT/15/5). Her use of activities from earlier

iterations of the same unit can be seen as the product of such reflection: reflection had identified them as useful for introducing syntactic knowledge.

T2 developed substantive knowledge through reading and use of the internet. Her knowledge of resources, which forms part of curriculum knowledge, guided this development. Syntactic knowledge was developed largely through reifications of practice, sometimes perpetuating omissions inherent in such documents. Knowledge of student difficulties was developed through repetition of units over time, while syntactic pedagogical knowledge appeared to be developed through a process that combined syntactic and general pedagogical knowledge with reflection on the effectiveness of the resultant activities.

5.4 Student perceptions of learning

The final research question for this study sought to investigate the influence of teacher knowledge on students' perceptions of their learning. An analysis of the data gathered for this case concerning students' perceptions of their learning is presented in this section. Student questionnaires and focus student interviews were analysed as described in Section 3.6.

5.4.1 Whole class questionnaires

The analysis of questionnaires is presented in Section 5.4.1. Twenty-five of the thirty students in Class 2 completed questionnaires at the end of the science fair unit.

5.4.1.1 *Utility and enjoyment*

The unit was generally seen as more useful for learning than it was enjoyable as shown in Figure 5.3.

Figure 5.3: Responses to student questionnaire, Q.11 and 12: Utility and enjoyment

The most common reason given for enjoyment was practical work. Five students found the unit boring. The results above are further substantiated by more detailed analysis of students' enjoyment of activities compared to utility. Responses are shown in Figures 5.4, 5.5, 5.6 and 5.7.

Figure 5.4: Responses to student questionnaire, Q.8 Part 1: Student enjoyment of science fair activities

Figure 5.5: Responses to student questionnaire, Q.8 Part 1: Student perceptions of utility for learning of science fair activities

Figure 5.6: Responses to student questionnaire, Q.8 Part 2: Student enjoyment of science fair unit activities

Figure 5.7: Responses to student questionnaire, Q.8 Part 2: Student perceptions of utility for learning of science fair activities

The activities enjoyed by most students were all practical. The trend was for more students to view activities as useful rather than enjoyable, but this was reversed for practical activities. The exception was students' own investigations, the activity enjoyed by most students (14) and also the one most (16) felt they learned a lot from.

The students' responses indicate they generally saw practical work they undertook as enjoyable but less valuable for learning, except in their own investigations. Activities designed to assist students to learn science procedures were seen as useful but not highly enjoyable. Similar results occurred for these aspects of their own investigations. An activity focused on interpreting results to form a conclusion was the least enjoyed activity. A long list of criteria for writing conclusions may have seemed tedious: "I will know I have been successful if I have: made a statement about how the results relate to the hypothesis; explained the results of my fair test ..." (Success criteria for writing a scientific conclusion/FN/28/6).

5.4.1.2 *Perceptions of learning*

Responses identifying new or interesting personal learning included planning a fair test (8), writing hypotheses, methods or conclusions (7) and controlling variables (6). Nine students identified empirical findings from their individual investigations as new or important, for example: "that insulating your home saves heat and money". One student noted "I didn't learn anything that was interesting" (Responses to Question 1, Student Questionnaire).

Figure 5.8 shows that when provided with a list of ideas or skills covered in the unit, most students reported improved or high levels of understanding for each area.

Figure 5.8: Responses to student questionnaire, Q.10: Student perceptions of learning given ideas/skills

Of the 25 students responding, 10 felt they successfully understood independent variables as a result of the science fair unit. Ten students also felt they had learned how to change one thing and measure its effect, although three students were still confused about this. Students reported successful learning about hypotheses (9), what a fair test is (8), and interpreting results and drawing conclusions (8). Three students were still confused over what makes a good investigation question although 15 students reported improved understanding of this.

5.4.1.3 *Perceptions of teacher effectiveness*

When asked about the effectiveness of their teacher in this unit, 14 students thought T2 very effective in teaching the unit. Sixteen students identified planning a fair test as the learning from the unit expected by their teacher, six students named specific aspects including hypothesis, method, results or conclusion. Figure 5.9 shows students' responses concerning the utility of T2's actions for their learning.

Figure 5.9: Responses to student questionnaire, Q.9: Student perceptions of utility for learning of teacher actions

Most teacher actions were valued to a certain extent by all students. The actions most valued tended to be explanatory or feedback opportunities.

5.4.2 Focus student interviews

Focus students were all Year 8 New Zealand Europeans in their second year at School 2. Two were female (C2FS1 and CS2FS2) and two male (C2FS3 and CS2FS4). C2FS1 had a high level of interest in science; the others were only moderately interested.

C2FS1's science interest developed from experiences at the Indian international primary school she attended for the first five years of her education and was encouraged by her family. She frequently watched scientific television programmes and sometimes experimented at home using a commercially prepared kit. C2FS1 enjoyed the science fair topic. She enjoyed developing appropriate methodologies for her chosen question and preparing her display.

C2FS2 saw science as important in building understanding of the natural world and informing world problems such as global warming. She enjoyed science documentaries on television. Her mother helped her with her science fair investigation. C2FS2 enjoyed some parts of the science fair unit. Despite having particular interest in her topic, she had struggled to develop her initial question into one investigable with a fair test and found this a negative experience. She enjoyed carrying out her own investigation but found writing the methodology and drawing conclusions difficult.

C2FS3 enjoyed practical aspects of science. He sometimes watched scientific television programmes but there was no interest or support for science at home. He enjoyed the fair testing unit for its practical aspect. He had chosen his topic from T2's list of questions because it seemed easy to do. He found the writing boring.

C2FS4 would sometimes look up science related topics and read about them on the internet. His stepfather had a science degree and supported him with his science fair investigation. He enjoyed developing his question and the presentation aspects of his work for science fair, but found writing the methodology and conclusion sections difficult.

All four students displayed moderate to high levels of on-task behaviour during observed lessons. All enjoyed the practical aspects of the unit, in particular carrying

out their own investigations. There was a sense of success and accomplishment in completing their science fair exhibits; they were all positive about their own work.

Focus students' responses concerning perceptions of their learning are summarised in Appendix M. Students all worked hardest on aspects of their own investigation. Their perceived learning reflects aspects emphasised in science lessons: writing an informed and reasoned hypothesis and controlling variables. Other syntactic knowledge was conveyed in this unit. C2FS1 and C2FS4 felt they had learned about the accuracy and integrity of the data collection process. C2FS1 commented that in doing fair tests in the past "I would maybe - like it would be getting dark or something so I would just leave out the last one or if I did my surfaces and it rolled and at the end of it, it just kept on rolling I would just say oh it stopped there" (C2FS1/I/22/6). She described how she now appreciated that all results needed to be measured accurately and if necessary the methodology needed to be adapted to facilitate this. C2FS2 also suggested the need for integrity in scientific investigation as important learning from the unit: "like you don't change your hypothesis to match your conclusion" (C2FS2/I/22/6). Three focus students identified the development of a consistent methodology as perceived learning.

Practising the steps of the fair testing process was viewed by these students as supportive of their learning:

Just doing the hypothesis and all that over and over again in different tests so that you could know how to write them...we did like 3 tests and we had to write hypotheses and the whole deal. So that got you ready to actually do the test. (C2FS1/I/22/6)

Maybe doing the fair test beforehand, because I hadn't done many - if any - fair tests before. So that gave me an idea of exactly how to do it. (C2FS2/I/22/6)

All four students commented on the usefulness of the success criteria and direction T2 provided, for example: "The talks about how to come up with an investigation question. That was good. What you had to include in it" (C2FS4/I/22/6); "The conclusion wasn't too hard because you did have success criteria" (C2FS2/I/22/6). They felt written feedback and conferencing promoted their learning: "I wrote the things out and then she just corrected it" (C2FS4/I/22/6); "[she] made sure everyone understood it and helped you - like conferenced with you and made sure that you were doing ok" (C2FS1/I/22/6).

These students accepted without question that the success criteria accurately represented scientific practice. C2FS3 said he worked hard at getting the hypothesis

and conclusion “right”, meaning aligned to the criteria. Similarly C2FS1 accepted that she needed to write a long conclusion addressing specified areas:

The conclusion was probably one of the hardest because she [T2] had success criteria that it had to be four paragraphs long and I just couldn't think of any more information to put into it. So I started like babbling and repeating things and then I finally like got it so that it was all evened out. Because on our interpreting results sheet we had one where you had to fill out all the boxes and then two of the boxes equal one paragraph. And so that really helped, like going over that. Like the question would be were there any surprises in your results? And I would write the surprises in my results and put it into the conclusion. (C2FS1/I/22/6)

Many of T2's understandings of fair testing processes were reflected strongly in these students' views of their learning. Focus students' perceptions of integrity of data and development of reliable methodology are also important understandings about the nature of science. These perceptions were not specifically made explicit by T2 in observed lessons, but appear to have developed as the students carried out investigations under her guidance. Her modelling of accurate measurements during class investigations suggested accuracy was expected science practice, so may have encouraged ideas of integrity. The pedagogies employed by T2 were seen as useful for their learning by focus students, who appreciated having clear direction and expectations in the form of success criteria. These criteria were accepted by students as being true representations of scientific practice. The significance of T2's syntactic knowledge is again apparent.

5.5 Summary

T2 demonstrated knowledge from each of the domains in implementing the fair testing unit. Her knowledge influenced science learning opportunities in a number of ways. The class was well managed and focused on science learning opportunities during lessons through use of strong general pedagogical knowledge. Her provision of success criteria, part of her usual teaching approach, made syntactic learning intentions very clear for students. Other significant influences were T2's general aims for her students and her process orientation to teaching science, part of PCK, which drew heavily on her syntactic science content knowledge and beliefs. While this domain included useful knowledge about fair testing steps as well as aspects about the nature of science, there were also limitations in that other forms of investigation were not considered.

T2 did not have a science background. She purposefully developed syntactic knowledge using reifications of scientific practice such as award winning exhibits at

the regional fair. The curriculum may have been a source of guidance. Omissions in curriculum documents and other reifications she accessed corresponded with gaps in her knowledge about the variety of investigations possible in science. T2 also used connections she had with members of the scientific community, such as the science fair judges for the school fair, to develop her knowledge. T2 combined general pedagogical strategies and her syntactic knowledge to create learning experiences for her students. She reflected on the effectiveness of the experiences, building PCK. She used PCK developed from earlier iterations of science fair units in the form of experiences she had found effective for developing particular aspects of fair testing.

In teaching the science fair unit T2 used approaches that could be considered sociocultural practice. Students practised the steps of fair testing, an authentic scientific investigation process, with direction and support from T2 that built toward independent use of the process in their own investigations. T2's use of a staged approach appeared almost developmental in nature in that students practised a step until she was satisfied with levels of competence before moving on to the next step. Opportunities for distributed cognition in the form of group activities were common, but also restricted by the authoritative nature of classroom discussion and the limitation of examples of expert practice to T2's own modelling and success criteria.

Students' perceived learning included the syntactic aspects of knowledge addressed explicitly by T2 in lessons. Focus students also developed other understanding about the nature of science including the need for accuracy and integrity in data gathering and the importance of developing reliable methodology, aspects not covered explicitly in lessons. Another finding from this case study concerned students' perceptions of the role of practical work. Many students enjoyed practical work but saw it as having low utility for their learning. Practical work was almost seen as a reward: fun to do but not particularly useful for learning, except in their own investigations.

CHAPTER 6

Case Study 3

6.1 Setting

Case Study 3 involved an experienced teacher and syndicate leader with responsibility for science, T3, in an urban school, School 3, teaching a science focused inquiry unit on fitness to her class of 30 Year 7 and 8 students.

6.1.1 School 3

School 3 was a primary school for Years 1-8 situated on the edge of a city central business district. Science units were usually taught twice per year. Inquiry was School 3's expected teaching approach. Inquiry is a teaching approach in common use in New Zealand primary schools promoting generation of student questions through immersion in a topic. The answering of student questions then forms the focus for learning. The whole school was involved in science inquiry during the observed unit. While six of the nine classes were exploring forces, T3's syndicate had decided to implement a science unit about fitness because students were keen to do more physical activity. The topic was new to the three teachers in the syndicate.

6.1.2 Class 3

Class 3 is described in Table 3.1, p. 56. Nineteen of the 30 students had attended School 3 for the whole of their primary education. The remaining students had attended up to two other schools. Two students had English as a second language (ESL). The class mostly engaged well: approximately three quarters of the students were on task most of the time. A small group of boys were easily distracted.

6.1.3 Classroom setting

Science was taught in T3's normal classroom. Students sat at tables for independent and group work and on the floor in a dedicated space for class discussions. Books from the National Library Schools Service relating to the topic were easily accessible. Whiteboards displayed daily timetables, notices and weekly spelling and were used to record ideas and display student work during class discussions. Student work in science and an ongoing record of the inquiry were displayed on the classroom wall:

In our science work we are learning about our bodies before we embark on our fitness inquiry...Tuning In: At this stage of the inquiry we talked about what we knew about fitness and our bodies. We began to ask ourselves some questions. (Classroom display, FN/21/5)

A small room off the classroom housed a set of six computers, connected to high speed internet, which students accessed as needed.

6.1.4 Teacher (T3)

T3 studied science right through secondary school in New Zealand but “I wouldn’t say it’s my area” (T3/1/8/5). Her teaching experience included six years running a unit in London for children excluded from school. Back in New Zealand she trained and worked in early childhood before returning to the primary sector to teach reading recovery. T3 later trained and worked as a resource teacher of learning and behaviour before becoming syndicate leader in School 3 where she was involved in school-wide professional development in science in 2005-6. T3 said she enjoyed teaching science, and together with another teacher, was responsible for science in the school.

6.1.5 Planning for the fitness science inquiry unit

Curriculum achievement objectives focussing on investigation from the Nature of Science strand and on “life processes” from the Living World contextual strand of the current curriculum (MOE, 2007) were recorded in the syndicate’s plan for the term. Students’ questions about fitness were elicited to inform initial planning. The three teachers in the syndicate together planned and implemented the immersion phase of the inquiry: students engaged in activities exploring the heart, lungs and muscles, noting their questions. Teachers then identified two conceptual goals for students: “that the human body is complex and remarkable” and “how maintaining and improving their personal fitness can enhance their quality of life.” Intended learning outcomes stated that students “would be able to explain their understandings of how the heart and lungs work and how they could be maintained as healthy organs” (Minutes of syndicate meeting, FN/20/5).

T3 saw planning as important:

Not necessarily exactly step by step....You have to have thought about what it is that you want them to learn and understand...you have to get things like the National Library books and you have to have organised buying things in advance so that you can actually run your lessons. (T3/1/22/5)

She also felt flexibility was necessary. Her own vision for the unit was modified as the inquiry developed:

That’s what the inquiry process is like. There’s only so much you can plan....I had some ideas I had thought we were going to do but, in actual fact, I made more a focus on investigation than I did, say, on researching and finding out about specific body parts and the body. (T3/1/29/7)

6.1.6 The fitness science inquiry unit

An example of a typical lesson summary from this unit, developed as described in Section 3.6, is included in Appendix N. Figure 6.1 shows the time spent on different learning experiences for observed lessons.

Figure 6.1: Time spent on learning experiences in Case 3

Most time was spent on group rotation through circuits of activities that included observation of animal organs and making models of hearts and lungs. Groups also spent large periods of time in practical investigations of fitness and gathering information for explanatory reports about organs and to answer student questions. Learning experiences were mostly socially interactive. Frequent use was made of 'peer share': brief focused discussion between pairs of students used to develop ideas or reflections that were expected to be shared with the class. For example:

What you're going to do is be real scientists here and you're not going to just do this once. You're going to do this three times. Why do you think I'm going to get you to do it three times? Talk to the person next to you, please...[30 seconds of discussion]... [Name], do you know why I might be getting you to do it three times? (T3/LT/21/5)

Class discussion was common and used by T3 to co-construct with students key features of scientific processes and communication. Lists of key features were jointly developed for observational drawing, scientific information reports, and investigation reports.

T3 spent a considerable proportion of time on instructions. She set clear expectations for activities so that groups could work independently. Class discussion often followed that consolidated instructions.

Several learning areas were integrated with science. Health and physical education provided the context for the science learning while science provided the context for English and statistics at various times during the unit.

The nature of science content and order in which it was covered is shown in Appendix O. In summary, the sequence illustrates that students' initial ideas and questions were first sought. Students were then immersed in a variety of activities about the body and fitness and developed further questions. Opportunities followed to learn about the structure and function of the heart and lungs and to answer students' questions. Finally, students developed group investigations related to fitness.

Day-to-day planning depended on what transpired each lesson: "I need to be reflecting on what I'm doing and then readjusting in light of what I've done" (T3/I/22/5). Student needs, identified by T3 as the unit progressed, influenced ongoing planning. "There were a whole lot of extra lessons that I had to put in because, in fact, I realised they didn't have enough information in order to do an investigation" (T3/I/17/7). Extra aspects addressed largely related to scientific processes and values, although student group skills also became a focus later in the unit.

Implementation and management of the unit required knowledge in a range of domains. The contribution of these domains, as exhibited by T3, is described in the following sections.

6.2 Teacher knowledges

This section describes the teacher knowledge evident during the observed unit. Knowledge domains are discussed in the order that they appear in the Teacher Knowledge Framework (Table 3.3, p. 65).

6.2.1 General pedagogical knowledge

The first component of this knowledge domain is instructional strategies and approaches. Section 6.2.1.1 describes T3's teaching approach. Section 6.2.1.2 describes sociocultural practices used by T3 as part of this category but also in investigating the third research question guiding this study. Subsequent sections describe classroom organisation, communication, and discourse.

6.2.1.1 *Teaching strategies and approaches*

As expected at School 3, T3 applied an inquiry approach for the observed science unit (Section 6.1.1). Student questions and ideas contributed to its direction and content. Prior to the unit T3 recorded students' questions and responses to "What could we learn about?" and "What could we investigate?" with regard to fitness (FN/30/4). Student questions continued to be raised and addressed throughout the unit (Appendix O).

T3's approach was sociocultural. Students participated in authentic investigations and were enculturated into scientific practices and values: "We think our kids need to be investigators and so we need to be providing opportunities to draw conclusions and to predict and come up with some understandings themselves: that's important" (T3/I/22/5). A sense of joint enterprise toward the inquiry was overtly fostered as were socially mediated forms of learning. Cognition was distributed over a range of tools and people.

6.2.1.2 *Sociocultural approaches*

T3 espoused a participatory approach to science learning:

I want them to actually feel like they themselves are scientists. So they're investigators and that they're data collectors...asking questions and then seeking answers and then trialling...(T3/I/22/5)

Sociocultural approaches employed in lessons were analysed as described in Section 3.6. A typical lesson analysis is provided in Appendix P.

Group work predominated, providing many opportunities for socially mediated learning. T3's constant roaming and monitoring provided opportunities for social mediation of individual learning. T3 emphasised how to become a social learner by making aspects of collaborative learning behaviour explicit (Salomon & Perkins, 1998): "They're all huddled close....They're looking at it together....You've got yourself into a position where you're working collaboratively" (T3/LT/18/5); "Both of you need to read it together....You need to agree with your partner" (T3/LT/21/5). She required groups to reflect on the way they had worked together. Individuals then set personal behavioural goals for next group tasks using co-constructed criteria:

Novice: I listen to some people's ideas; I am easily distracted; I find myself interrupting others

Apprentice: I listen to most ideas shared by others; I occasionally interrupt others

Practitioner: I listen to all and let them finish without interrupting them

(Criteria from group reflection task/FN/20/7)

Cultural scaffolding was used in ways that afforded both syntactic and substantive learning opportunities. Groups examined examples of scientific texts regarding heart and lung structure and function such as observational drawings, diagrams and scientific reports. With T3, the class then developed lists of key features of these scientific communication forms.

T3 encouraged participation in science, emphasising scientific values: "I want you to think of yourself as a scientist and scientists have really great, creative thinking ideas, but they also have a little bit of order and rigour to what they do" (T3/LT/18/5). Authentic activities in which students participated included careful observation, accurate recording of observations, orderly documentation of methods, developing explanations based on observations, critique of others' work (observational drawings and investigation reports) and interpreting data (See Appendix O). In groups they planned, implemented and reported on investigations, encountering and solving the inevitable methodological problems that occurred. Students and T3 participated incidentally in conjecture and debate, as illustrated below.

T3 (restating a student question from the beginning of the unit): Why is the heart on the left side?

S1: I know that the left lung is smaller for the heart on the left side. I don't know why it's smaller.

S2: It's more likely to be the other way round: the lungs are smaller because the heart's there.

T3: Is it the chicken or the egg?...I'm kind of interested, why did it go on the left side [wondering]?

S3: Maybe because your stomach's more to the right so you've got heaps of space. (LT/3/6).

A sense of joint enterprise was evident, fostered through T3's repeated use of "we" and "our" and positive affirmation of student contributions to discussion. Student ideas were included in protocols and lists of key features and their questions were identified and addressed. Groups carried out their own practical investigations with regard to fitness.

Staged tasks were used by T3 to emphasise orderly documentation of methods: she described and monitored each step as students carried out and documented the sweaty hand investigation (Appendix O). Later, T3 identified from their initial efforts that students needed support in developing the pattern seeking type of investigations needed to explore fitness. She staged the tasks involved in this type of investigation by getting students to first practise data interpretation using sets of previously collected data before continuing with their own investigations: "We're just practising this...practising interpreting" (T3/LT/29/6).

T3 provided expert examples from books of scientific texts and diagrams for students to analyse. She modelled scientific methods such as repeating and averaging measurements when measuring lung capacity. T3 also modelled the thinking needed in investigations:

You need to decide what four students you want to test. Are they going to be four year eights, two boys, two girls? Are they going to be four year eight girls? Are you going to take all year five students or year five and year six? Are you going to take just 11 year olds? (T3/LT/22/6)

Her own scientific surmising was made explicit as were student examples of such practice:

When I was playing around with these [sheep lungs] the blood, in fact, was pink...why do you think that might be?... I'm thinking, I'm surmising that yesterday the blood in the organs was really pink because it had oxygen in it. (T3/LT/14/5)

I just heard [Name] over here, she's also surmising. She's saying "I think guys are stronger and girls are more flexible." Let's see. That'll be interesting. (T3/LT/22/7)

T3 enculturated students into the use of scientific vocabulary, text, processes and values. Students collaborated with T3 to identify key features of scientific texts such as diagrams and scientific reports prior to using them to convey ideas (Appendix O). Scientific vocabulary introduced included: atrium, ventricle, aorta, pulmonary vein,

trachea, bronchi, bronchiole and alveoli. Terms were included in spelling lists and linked with their structure and function as students explored animal organs:

T3: So the air comes down here and goes on to each side, here, to the bronchus and they're further divided up into bronchial tubes that branch off, little branches and then they come right to the very end of the lungs, out around here, and they have little clusters of, does anyone know what they're called?... It was a spelling word that [Name] chose. Alve-

S1: Alveoli

T3: Alveoli and they are only the size of a pinhead. Lots and lots and lots of them. In fact, 300 million of them, and they look like bunches of grapes. (LT/21/5)

"Like bunches of grapes," used in the above excerpt, is an example of instructional congruence: linking to students' existing experiences to assist enculturation. Choosing school contexts for fitness investigations and investigating personal attributes like students' lung capacities were further examples of its use.

Students were enculturated into the following scientific practices through participation: interpreting and creating scientific diagrams; observation; interpreting data; developing explanations; locating and structuring scientific information into a formal report; and planning, carrying out and reporting on investigations requiring interpretation of quantitative data (Appendix O). Teacher led discussion emphasised scientific values as the need arose:

T3: Write down anything that you see happening in your bag....Why is it that I'm discouraging you from patting and stroking your hand?

S1: Because it changes the effect

T3: It does change the effect...What would change about it? What might you do to your hand if you keep stroking it?

S1: Make it hotter

T3: You're making it hotter, fantastic. And we don't want that. We just want to watch what happens [at rest], so just leave the bag completely. (LT/18/5)

T3 made use of several forms of guided participation. Her selection of active and relevant activities meant students chose to participate in learning opportunities. She frequently structured students' direct interactions with scientific processes. An example was introducing fitness investigations: the broad nature of the investigation was set by T3 and students made choices within that. T3 also provided guiding questions, indicating the factors about which students would need to make decisions: "You will need to decide: what exercise the students will do and for how long, what other observations you might need to take and record, how to record your data" (Investigation planning sheet/FN/22/6).

Mutual bridging of meanings was used occasionally, for example a term invented by a student for lungs, “breathing machine”, was used by T3 in class dialogue to facilitate understanding. Narrative, using T3’s personal stories, was used rarely; role plays and routines were not observed.

Analysis of data for distributed cognition revealed that the full range of tools was made available to students to think with. Students worked with each other, and used symbolic tools such as books and technological tools including computers and calculators. Additionally, natural objects, including fresh animal organs, were made available to support thinking; students investigated their own fitness and that of other classes. Studying natural objects modified students’ prior conceptions, as exemplified in the discussion following examination of sheep lungs:

T3: What did you learn [S1]?

S1: I thought the lungs would be more like the picture...I thought they were going to be flat like a tombstone. (LT/21/5)

Several such examples occurred during this discussion. Developing understanding about the natural world is the whole enterprise of science and therefore should have been an expected feature of science lessons. Natural objects had not been included as a category of distributed cognition until its prevalence in this case. Previous cases were subsequently analysed regarding its presence.

The evidence presented shows T3’s sociocultural teaching approach, especially participation and widely distributed cognition, afforded multiple opportunities for both substantive and syntactic science learning. Her participatory style appeared her normal approach, not a special approach for science. Inquiry was the school’s usual approach for topic studies such as social studies and health, as confirmed by focus student interviews. Participating in the practice of different disciplines also appeared usual: T3 was heard referring to students as writers and mathematicians.

6.2.1.3 Classroom management and organisation

Figure 6.2 shows the frequency of use by T3 of components of this knowledge. The major features of this analysis are presented and discussed below.

Figure 6.2: Frequency of observed use of knowledge of classroom management and organisation by T3

The high frequency of feedback was a feature of T3's classroom management. This was largely in the form of positive responses to student contributions to discussion, helping build the observed sense of joint enterprise. Class feedback made expectations regarding scientific values and practices explicit: "...the recording that you did was much more thorough. It was really great to see you've given an explanation...your diagrams were a lot clearer" (T3/LT/18/5). Written individual feedback was used to improve achievement: "Given the feedback I gave you ...turn to the person next to you and tell them what your goal is for improving your lung research work" (T3/LT/9/6).

T3 monitored student performance continually through use of interactive class discussion, roving during activities and regular marking of work, which informed her feedback and further teaching. T3 structured students' interaction with scientific processes and information as described in Section 6.2.1.2. She linked back to prior experiences, often at the beginning of lessons, giving a sense of flow and direction as well as providing context and purpose for the forthcoming session.

T3 gave detailed instructions for activities students were to complete independently. Student ideas were incorporated into expectations for both social and scientific behaviours through co-construction, as described earlier. Behavioural issues were met with a swift response by enacting consequences.

T3's knowledge of classroom management meant students were engaged in science tasks for substantial periods of time. Planned teaching in other learning areas was deferred several times to allow science activities to continue.

6.2.1.4 Classroom communication and discourse

An interactive dialogic approach was the predominant form of discourse observed in Class 3. Student responses and ideas were sought and celebrated. T3 often paraphrased students' statements, checking her understanding and making ideas available to the class:

T3: Okay S1 what else should I be looking for in an excellent drawing?

S1: You'll see the key points...to do with the thing, like, the skin.

T3: Ohh, right, okay...so you're saying there's a written explanation with it?

S1: Yeah

T3: So what you're telling me, there's both pictures and words? Great!
(LT/18/5)

Inaccurate ideas and responses were welcomed as worthy of further inquiry:

S1: I thought it [heart] was the biggest muscle in your body.

T3: Well that's a question though, isn't it? What is the biggest muscle?
(LT/14/5)

T3 expected students to contribute to class discussions. Use of peer discussions helped students develop ideas they could contribute to class discussion. She used interactive dialogic discourse for feedback from group and peer discussions and co-construction of key features and criteria, contributing to the sense of joint enterprise observed during the unit.

A more authoritative dialogic approach was used to clarify and emphasise important points:

T3: What's going to be recorded on the table?

S1: Information

T3: What kind of information?

S1: Data

T3: What is the data you're collecting?

S1: The pulse

T3: So you're going to record pulse. Great. What else is going to be recorded? Am I just going to write down a whole random lot of pulses? What's going to be on that table?

S2: Names

T3: Thank you. (LT/22/6)

This approach was commonly used as T3 roamed during activities, monitoring individuals and groups. She focused her questioning to ensure students articulated important ideas.

A non-interactive authoritative communicative approach was often used for periods of review or instruction at the start of lessons. Short commands or targeted questions during activities reminded students of expectations. These were often phrased in the first person, contrasting with the emphasis on student ownership and responsibility for learning: "You need to record how you made a model lung and you need to draw me a well labelled, large diagram in your topic book showing me what your model lung looks like" (T3/LT/27/5). This encouraged student accountability to T3 for completing work to agreed high standards.

In summary, T3's general pedagogical knowledge, in particular her sociocultural approach and management of discourse, provided many opportunities for science learning and enabled her to engage and maintain students' focus on science.

6.2.2 General aims, purposes and values of education and assessment

T3's aims for her students closely aligned with the key competencies described in the current curriculum (MOE, 2007): "...to be independent, to be self-managers...I really like having the key competencies to work from" (T3/I/8/5). She also wanted them to: "...be excited learners...to have passions" (T3/I/8/5). Her positive responses to students' ideas described in the last section encouraged such attitudes, as did the use of student questions to direct learning. She required students to frequently review and identify ways to improve their learning, a way of achieving her goal of developing self-managing learners.

T3 believed that a purpose of education at this level was to introduce a range of disciplines that may spark interests or careers:

I think that we have to introduce them to all aspects of the curriculum and all areas: history, geography, science, absolutely everything. They need to have tastes and nibbles at it all. We might have a vet amongst our group after all of this; we might have two neurosurgeons. (T3/I/8/5)

Her aims for science education in Years 7 and 8 were similar:

That it's enjoyable: connected to everyday life. Something they could consider going further in, offers career and study opportunities...to make sure I give them a range: coverage....I want to be igniting an interest and them asking questions, seeking answers and collaborating with me to come up with ways to test out our theories and our thoughts. (T3/I/22/5)

She felt that one purpose for science education was to build perceptions of science, rather than detailed knowledge:

I don't think they're going to necessarily remember, in a couple of years, that there's atria and ventricles in the heart. But I think what they'll remember is that they had a time when the teacher brought those things in and, ooh, it was awful, or ohh, it was really cool. (T3/I/22/5)

T3's expressed aims to students were both syntactic and substantive: "I want to start training you to be observant scientists...I'm really interested in increasing your knowledge of anatomy... to make sure you can all identify where your heart is, how it works, its key parts" (T3/LT/25/5). These aims were evident in her practice as shown in Appendix O.

The transition to secondary school was a consideration:

I'm introducing them to recording an investigation: I think they should know about that...I try to introduce vocabulary, scientific vocabulary so that certainly my ESL students meet it before they get to secondary. I do shared reading of scientific type texts, tables, charts, those things because, actually they need to have had experience of that before they get to secondary. (T3/I/22/5)

T3 used assessment to improve student learning, firstly through informing next teaching:

Collectively, you were very poor in recording your scientific investigations last week and because of that, we're going to redo one of those investigations together at the same time in order for us to actually hammer it and nail it. (T3/LT/18/5)

Secondly assessment informed the specific feedback and personal goal setting described in Section 6.2.1.3.

T3 also saw assessment as a means of showing student progress to inform school evaluation and review and held strong beliefs about the nature of the assessment that would do so. When requested by the principal to provide summative assessment data on substantive knowledge growth for school review she expressed concern that such data would not serve this purpose well. She suggested data she had collected recording syntactic aspects, such as students' ability to process and interpret data, would more effectively show ongoing progress in science and inform school review (FN/29/6).

T3's expressed aims for general and science education were manifested in her practice, creating opportunities for students to recognise and participate in the discipline of science. Her knowledge and beliefs about the purposes of assessment meant it was used to improve students' use of scientific practices and knowledge along with their general learning skills.

6.2.3 Learning and learners

T3 believed strongly that an inquiry approach benefited learning: "I think asking questions and trying to work out ways of answering them yourself is much better than being told definitive answers" (T3/I/8/5). She also believed that practical experience was important for learning: "What I really wanted them to do was to have hands on, actually touching organs...because I think that it's easier for them to understand if they can actually physically touch it and see it" (T3/I/8/5). This belief was not particular to science education:

I think it has got benefits for science but if anything was occurring, it was that I felt that it would be better for them to actually see it and actually have hands on opportunity to touch something: look at it and explore it. (T3/I/8/5)

She believed seeing real organs was engaging: “It’s captured them...they are quite keen...it’s created a need to know” (T3/I/18/5). T3 thought students learn “when they’re engaged, when they’re excited, when they feel like they’ve got some ownership of what they’re doing, when they understand the purpose or the reason why they’re doing things” (T3/I/22/5). She helped students to consider purposes in science: “I want you to talk to the person next to you about why it’s really important to be able to record what you see happening” (T3/LT/25/5). Student reflection on learning was a feature of T3’s practice. For example, she asked students to formally record evaluations of the value for their personal learning of different experiences: direct observation, making and using models, experimenting and researching and reading from a range of sources. Encouraging such reflection is congruent with her view that students learn when they have ownership and developed her goal of creating independent learners.

Frequent use of group work and class discussion as shown in Figure 6.1 (p. 143), reflected T3’s beliefs about their importance for learning: “They [students] need lots of opportunities to talk about what they’re doing and they need opportunities to share their ideas and work collaboratively or in a group process...co-constructing” (T3/I/22/5).

Written work was seen to support science learning:

They do need to be able to record an experiment and their observations and...to record data because sometimes you have to come back to it....So I think all of that’s valid: to synthesise and analyse the data we’ve gathered, I think that’s fine....I’m not into cloze texts where they fill in the gaps. (T3/I/22/5)

These comments suggest T3 thought learning occurred through participation in authentic written activities, learning to use scientific text as it is used in science. As well as recording methods and observations, students identified key features of scientific texts such as diagrams and used them to convey their developing substantive ideas as described in Section 6.2.1.2.

T3 felt her behaviour influenced learning: “I think I need to be enthusiastic....They learn if I’m prepared and organised” (T3/I/22/5). It was “important to learn alongside students: how can we learn about this together?” (T3/I/22/5). T3’s use of co-construction exemplified the enactment of these beliefs in the classroom. T3 thought

of herself “like a facilitator” but “sometimes I’m the person who says ‘We have to do these parts. These are the non-negotiables.’” (T3/I/8/5). This view corresponded with her use of authoritative dialogue to emphasise key points and expectations.

T3’s beliefs about learning were enacted in her practice. Whilst all of these beliefs supported science learning, belief in the importance of experiencing real objects and authentic written activities for learning facilitated many syntactic as well as substantive learning opportunities.

6.2.4 Educational context

Within this domain it was T3’s knowledge of the school community and students that most supported her science teaching. Knowledge of school organisation allowed her to organise teacher release time so that the teachers in her syndicate could plan together for science, thus enabling sharing of ideas, activities and resources. Knowledge of the parent community facilitated science delivery: “What I did was send a note home so that parents knew that their children were going to be handling organs and if there was any objection” (T3/I/8/5). She knew which parents could help with particular resources: “I’m just going to put this piece of tubing here. Courtesy of your Dad [Name]!” (T3/LT/21/5).

Sensitivity to New Zealand’s bi-cultural context was demonstrated during the unit:

[Teacher of Māori descent] was a little anxious about the organs initially and said that she would feel okay about it as long as we were treating the organs respectfully and we weren’t going to just waste them. So we’ve negotiated with a member of staff who’s got a dog...the meat will be cooked up and used and that dog will be fed. So culturally, we’ve explained that to our parents in the letter I sent home. (T3/I/8/5)

This process was explained to students. T3 led Class 3 in karakia for kai (prayers over food), spoken in Māori, before break and lunch. She used a variety of Māori greetings when taking the roll. Mornings began with pānui (news) and waiata (songs). No other links to Māori culture were apparent during science.

T3’s knowledge of students had informed the selection of topic:

I thought that [fitness] would be something that would capture some of my disengaged kids. I thought I’d get more buy-in and I thought it would be something that my ESL students would understand more than wheels. (T3/I/8/5)

Knowledge of her students meant T3 quickly attended to ESL students at the beginning of tasks ensuring they were usefully engaged. She was mindful of some

students' apprehensions concerning organs: "I've got gloves as some of you don't particularly like the idea of touching meat" (T3/LT/14/5) and knew who was genuinely upset: "[Name], if you don't want to take part in this, you can move away from the table, darling" (T3/21/5). She later checked on this student in the bathroom.

Frequent marking and deliberate strategies built knowledge of students:

Maybe there are two questions that are really burning a hole in your head and you really want to know the answers to, so I want you to use the asterisk so when I look I'll say, ah huh, [Name] is very keen to explore blah. (T3/LT/14/5)

Knowledge of students informed group composition to optimise learning: "Some are excellent leaders but like to take over and do everything; some need to be allocated a task so they are contributing" (T3/FN/5/7).

T3's knowledge of context facilitated opportunities to develop her own knowledge for teaching and locate equipment as well as provide science learning opportunities appropriate to individual needs and sensitivities. This facilitation was supported by her ability to recognise opportunities for science learning. T3's science content knowledge is described next.

6.2.5 Science content knowledge

The fitness science topic was new for T3. Nevertheless she supported students to develop knowledge of the circulatory system and investigate fitness scientifically as described in Section 6.4. This competence depended on T3's syntactic beliefs, knowledge of science investigation, and identification of relevant substantive knowledge.

6.2.5.1 Syntactic knowledge and beliefs

T3 demonstrated a range of syntactic knowledge and beliefs.

A frequently stated belief was the need for accuracy and rigour in gathering and recording data. T3 insisted on orderly planning and recording as scientific attributes:

I want them to be able to record data accurately...drawing accurately what they see. (T3/I/8/5)

Some of them, they were repeating the exercise but they'd only written down one column. So I said 'But you've got them repeating this. How many times have you got them repeating it? Ohh, three. So how many times do you take a pulse? Ohh, four. Where are the four columns?'...which is what scientists would do. (T3/I/22/6)

Students were adjured to “look closely” and “draw what you see” (T3/LT/14/5). A lesson was developed to practise accurate observation: “I’m interested in you writing down what you actually see happening...many of you told me what you *thought* was happening...(T3/LT/25/5). The scientific reason for careful observation was made explicit:

T3: Why do scientists need to be sure tricky observers? Why do they need to use their eyes?

S1: They need to look carefully or they might miss something.

T3: So we’re looking for precision and you might lose data. Fantastic. Give me another reason, [S2], why scientists have to be really good observers.

S2: Because they need evidence that they’ve done that.

T3: Right, evidence. Great, fantastic. [S3?]

S3: This is a bit random but, like, to give someone who’s reading an observation to get a picture in their head of what it looks like.

T3: Great. So they need to be quite precise so that others can follow their thoughts. (LT/25/5)

Underpinning T3’s beliefs about observation was an understanding that science must account for all natural occurrences. There are no ‘incorrect’ experimental observations:

I’d anticipated that certain things would rot faster than other things. Sometimes it worked and sometimes it didn’t and I shared with them: ‘When I read up about it, it said that it would take X amount of time for the banana to actually rot and it’s funny because, in fact, it’s not been the case.’ So we looked at why, maybe our bananas rotted faster – what was it about our conditions – than in other compost? And that’s okay, sometimes scientists don’t get the results they anticipate. (T3/1/8/5)

This statement suggests T3 believed that science theory is contestable. She reinforced students’ views about possible conflicting opinions within science, while indicating that there may be agreement about some ideas:

S1: There might be different opinions.

T3: Brilliant. Less so probably in this kind of research...although there might be conflicting opinions if we were looking at how you make your heart healthy? (LT/ 26/5)

She suggested that new evidence can challenge existing theories: “I’m not convinced about the article that [Teacher name] heard which was if we tell our goals out loud, that maybe we don’t then achieve them. We might need to do some research on that” (T3/LT/9/6). T3’s belief about contestability led to students planning ways to test a theory expressed during the physiotherapist’s talk:

She said it took the brain 2000 repetitions so that your brain and body remembered how to do a particular task and she talked about elite athletes having to learn over and over, how to do something. So you are going to be investigating that. (T3/LT/22/7)

T3 engaged students in many forms of scientific investigation: exploration of organs, controlled investigations (sweaty hand and learning a new physical skill), making models, and pattern seeking investigations (comparisons of lung capacity and fitness between student groups). She exhibited useful procedural knowledge, modelling orderly recording and emphasising the need for controls:

We've got complete beginners who we're going to take through a process that they've got to practise over and over at a certain part of the day for short spells. What are we going to need in order to see what difference we've made?...How are you going to know if lots of repetition works? [Student responds]...That's really great: you need a comparison group. (T3/LT/22/7)

She saw the need for control as significant learning about science for students: "That's been interesting for them, they realised they had to actually exclude some of the data they'd collected from certain students because they hadn't applied the same parameters to gather the data" (T3/L/17/7).

T3 recognised that averaging multiple measurements improved validity of data:

Why do you think I'm going to get you to do it three times? Talk to the person next to you, please... So you're going to do it three times and you are going to find the average of your lung capacity. (T3/LT/21/5)

She also knew that a smaller range of variables and greater sample size would produce more reliable data: "I think you need to look at the kids that you're collecting your data off...you need to have a bigger group but a smaller number of sub-groups" (T3/LT/28/6). She publicised students' efficient data handling to the rest of the class: "As you're pulling out information, you're putting ticks by people's names. Why? [S1 explains]...Brilliant, you're keeping track of which data you've used" (T3/LT/23/6).

The importance of interpretation and theorising in science was recognised: "They haven't tried to analyse what they've done...They weren't interpreting the data" (T3/L/17/7); "Yesterday we focused on 'how' we collected data in an investigation. Today we are going to focus on 'what' we actually do with the data we gather" (Lesson plan/FN/23/6). Students were not given accepted scientific explanations. They were asked to interpret evidence for themselves using their current knowledge: "Why did your hand become sticky or clammy? Why did your bag fog up? Write down why you think it happened" (T3/LT/18/5). Surmising was made explicit as a scientific behaviour as described in Section 6.2.1.2.

The features of successful scientific investigations were co-constructed with students. These included being planned, sharing ideas, working together and being flexible and adaptable.

T3 displayed knowledge of a range of ways to investigate in science. Her syntactic knowledge and beliefs meant she recognised when and how to improve students' investigation practices and utilised opportunities to test theories and make scientific values explicit. Much of this syntactic knowledge was not originally intended learning. It was highlighted in response to T3's observation of students' practice of science. Her participatory beliefs, engaging students in investigating the natural world, activated T3's syntactic knowledge.

6.2.5.2 Substantive knowledge and beliefs

T3's knowledge of general concepts and topics allowed her to recognise the relation between fitness and the respiratory and circulatory systems: she focused on heart and lung structure and function within the study of fitness (Appendix O). She knew an important principle for students to understand was that the heart is a muscle that pumps oxygenated blood around the body. This focus was evident throughout the unit, for example when exploring the heart and lungs together: "It [heart] pumps it furiously, all that beautiful oxygenated blood, blood that's got oxygen in, and it pumps it...so it's on its journey around the rest of the body" (T3/LT/21/5). The reason for the need for oxygen by the body was not highlighted, a possible gap in emphasis, if not knowledge, that may have consolidated the connection with fitness.

Topic specific content knowledge was developed as required. T3 commented that this topic was "way beyond her comfort zone" and that she had been "reading up about the lungs at 6am in the morning" (T3/FN/21/5). Nevertheless she was able to accurately locate the following structures with students as they explored organs and constructed diagrams: trachea, bronchi, bronchial tubes, bronchioles, alveolus/i, the aorta and the pulmonary vein and artery, heart strings (chordae tendinae), the left and right atria, and ventricles. It was apparent when she explored the lungs with groups that T3 understood that air went down the trachea and through the bronchi to bronchioles and alveoli where it met blood vessels. She prompted students to consider the protective function of the ribs and to identify the cartilage rings in the trachea. She knew that the lungs sat in front of the heart and highlighted the thickness of the ventricles:

T3: So down here, remember how we saw when we sliced the hearts, one of them, the walls were thicker down the bottom. Why do you think the ventricles are thicker? What do they have to do with the blood?

S1: They pump.

T3: They do the pumping, fantastic. So why are they thicker then, if they're doing the pumping?

S1: Because they've got to be strong. (LT/21/5)

T3's content knowledge was not broad; she was unable to answer a student's question about where the oesophagus went, but suggested ways they could find out. She did not use the opportunity of identifying the rings in the trachea to point out their important function of keeping the airway open. She did not explore the body's need for oxygen or elimination of carbon dioxide. The only non-target content knowledge expressed was about evaporation of water.

Despite the newness of the topic, T3 identified important general concepts within it and demonstrated detailed topic related content knowledge that supported the development of key concepts.

6.2.6 Curriculum knowledge

As described in Section 6.5.2, T3's educational aims closely aligned with those outlined in *The New Zealand Curriculum* (MOE, 2007), released 18 months prior to the unit. The relationship appeared serendipitous rather than intentional, although she said she enjoyed working with this document. Her aim that students become "excited learners" and "have passions" (T3/1/8/5) links well with its vision statement for young people to "be confident, connected, actively involved, and lifelong learners" (MOE, 2007, p. 8).

T3 made behaviours useful for learning in groups explicit, for example in a personal goals chart on display: "Completing tasks I offer to do or that have been allocated to me so that our work is completed in the allocated time" (FN/23/6). Such behaviours align well with *The New Zealand Curriculum* key competencies that T3 liked "to work from" (T3/1/8/5): "Students who manage themselves...manage projects...[develop] a capacity to contribute appropriately as a group member..." (MOE, 2007, pp.12-13). T3 applied the competencies when focusing students on improving their abilities as group members:

T3: Okay think about your goals now... did you action what you were trying to do? [S1] you were focussing on what?

S1: Staying positive and contributing to my group

T3: Great. Who's in [S1's] group? Would it be true to say you were each involved and [S1] was definitely contributing? (LT/23/6)

Beliefs expressed by T3 about what to teach for science matched the focus of the science learning area of the 2007 curriculum where the contextual strands are seen as a context for learning about the nature of science. This direction in curriculum did not appear to drive her intentions, however:

I hope that they might be slightly excited by the fact that they've had real organs in the classroom and they've just had a slight taste of what it's [science] like...there'll be a Living World aspect to it...I saw there was potential for them to set up investigations, to hypothesise and to make some plans and test out some theories... I think, probably I'm looking at nature of science as more my focus, I think, if I was truthful. (T3/1/8/5)

Her planning recorded Level 3/4 Science Achievement Objectives from the 2007 curriculum:

NS: Investigating in Science – students will ask questions, find evidence, explore simple models and carry out appropriate investigations to develop simple explanations.

LW: Life processes: recognise that there are life processes common to all living things and that these occur in different ways. (Science Inquiry Plan/FN/8/5)

Intended learning with regard to the Nature of Science objective was not recorded in the plan, but T3 supported students in raising and answering questions, observation, exploration, planning investigations and interpreting data, thus connecting well with the document's intention. She also incorporated a variety of investigation types: making models, exploration, and pattern seeking as well as introducing aspects of fair testing, forms of investigation suggested in the aim of the investigating substrand in the 2007 document (<http://nzcurriculum.tki.org.nz/Curriculum-documents/The-New-Zealand-Curriculum>). These investigation types were also suggested by Goldsworthy et al. (1998), an article used by T3 to review science investigation at the school in 2006 (Science investigation review/FN/30/4).

The Living World objective was further interpreted as key ideas that students were expected to develop:

Children will:

Explain their understanding of how the heart works (circulation)

Explain how the heart can be maintained and improved as a healthy organ

Explain their understanding of how lungs work (respiration)

Explain how their lungs can be maintained and improved as a healthy organ.
(Science inquiry plan/FN/8/5)

These ideas were covered in lessons (Appendix O) and would contribute toward meeting the curriculum objective, although commonalities and differences between

the processes in different organisms were not discussed. The ideas covered match more closely the Level 3 objective from the 1993 curriculum: “Students can investigate special features of common animals and plants and describe how these help them stay alive” (MOE, 1993a, p. 58). Work on annotated diagrams also reflects curriculum assessment examples from the older document: “Teachers and students could assess the students’ ability to identify the different parts of a plant and describe their functions, when the students label, and annotate, a diagram of a flowering plant” (MOE, 1993a, p. 59), indicating, perhaps, that ideas embodied in the superseded curriculum were more entrenched.

Application of curriculum reflected both current and superseded documents. T3’s focus for the unit may have reflected accumulated curriculum knowledge or personal beliefs about what it was important to learn in science. Perhaps both were intertwined.

T3’s beliefs about vertical curriculum included that scientific knowledge would “get reinforced and confirmed when they get to secondary school” (T3/I/22/5). In providing real organs to investigate, T3 thought she had given students “a slight taste of what it [secondary science] is like. And lots of them did immediately say ‘Just like secondary school’” (T3/I/8/5). She believed the scientific skills she was teaching would be useful later for science: observational drawing was seen as “a valuable thing for them to be learning for secondary school” (T3/I/8/5).

With regard to horizontal curriculum, T3 saw science as being “connected to everyday life...inter-related with other things that we’re doing in class” (T3/I/21/5). She believed integration with other learning areas was “much more authentic: more purposeful and meaningful” but it was important “that you’ve got some really clear science goals and learning outcomes...as long as you’re assessing in each area.” (T3/I/22/5). She felt the health and science learning areas informed each other: “Some of it [health] is to do with science because of recording data and using measurement and then...what does that say about you? Where are you at?” (T3/I/21/5). Her practice reflected these views. The health area was linked into science diagnostic and summative assessment tasks: “I know my heart does the following things...I can keep my heart healthy by...” (Assessment task/FN/8/6). Students’ science investigations were about aspects of fitness.

Science was also used as a context for learning in English: “I try to link my literacy to my science so it’s an integrated approach” (T3/I/22/5). Students were encouraged to

use parts of speech to locate key science ideas in preparation for writing a report on the structure and function of the heart:

T3: What are the key things we highlight? [S1] you're amazingly fast...
Nouns. Naming words. Fantastic... Second thing, [S2], we highlight?

S2: Verbs

T3: Verbs that explain actions, things that the heart does. Brilliant. And the third group of words that help us to understand about the heart might be?...You're amazing. We're looking for descriptive words that describe the heart. (LT/26/5)

Note taking and summarising, which are literacy skills, were assessed within this science context: "Student can identify key phrases, topic specific words and key ideas to highlight prior to note taking" (Assessment form/FN/17/7). Science also provided a context for developing spelling knowledge: "Spelling notebooks please and you'll need your topic [science] book because some of you have got corrections: I want those words put into your spelling notebooks" (T3/LT/18/5).

The literacy needs of ESL students were addressed through the science context:

Hello [S1]...'I used a balloon for my lung.' Good boy! 'Whole glove.' That's got a silent 'w' that one: there are two 'w/holes'. For a whole glove it's a 'w' at the front and then a silent 'e'. You got all those letters. That's really good work. (T3/LT/27/5)

T3 recognised opportunities for "incidental maths": in recording their pulse rates students needed to "time it for 15 seconds and turn it into what would it be for a minute" (T3/I/8/5). She highlighted opportunities for learning in statistics: "I thought we might be able to see the average [lung capacity] for the class and the r-r: yes, the range! I thought it [measuring lung capacity] would give us some statistical information" (T3/LT/27/5). She also recognised when learning needs would be better addressed through statistical rather than scientific investigation:

Really, what I wanted them to be able to do was deal with another lot of data ...analyse it in groups and draw some conclusions and I thought I can do that in another much simpler way and it's still related to health and fitness...so now we're going to conclude it, by them doing this in maths for three weeks. (T3/I/29/7)

T3's knowledge of resources included teaching materials and everyday equipment useful for science. T3 knew how to obtain relevant books from the National Library from which she identified useful activities, diagrams and models of scientific reports. She knew which books contained information useful for students. After discovering their existence from a colleague, T3 used the *Science Exemplar Matrices*, a

resource provided by the Ministry of Education (2004), when assessing students' investigation skills. Her assessment records quoted from these directly (FN/22/7).

Knowledge about everyday equipment useful for science within the school helped T3 implement science. This included stopwatches, knives and plastics gloves. She used Pyrex bowls in steam experiments because they "sustain heat well" (T3/LT/25/5). She used a plastic bottle and hose to enable students to measure their lung capacity, getting the technology teacher to drill the holes necessary in the lids. She knew to obtain sheep hearts and kidneys from the butcher and lungs from the abattoir. During investigations T3 acted as an equipment facilitator, ensuring groups had the equipment they needed, offering her mobile phone when there were insufficient stopwatches (FN/29/6).

T3's knowledge of resources supported students with scientific investigations and gathering scientific information. Her horizontal knowledge and beliefs enabled her to combine learning opportunities for science with learning in other curriculum areas. Content covered aligned with aspects of both old and new curriculum documents. T3's focus on syntactic science aspects and learning skills matched the intention of the 2007 document, but whether or not decisions to include such content derived from knowledge of New Zealand curriculum documents is uncertain: choices appeared to relate more to T3's beliefs about learning. The science content she chose to deliver, described in Section 6.2.5, was a significant influence on science learning opportunities, as was her pedagogy. The PCK T3 employed during the unit is described next.

6.2.7 Science pedagogical content knowledge

T3 demonstrated a guided inquiry approach to science teaching in which "the teacher and students participate in defining and investigating problems, determining patterns, inventing and testing explanations and evaluating the utility and validity of their data and adequacy of their conclusions" (Magnusson et al., 1999, p. 101). Appendix O shows that students were involved in each of these activities at some point during the unit. It was T3's belief that worthwhile science education involved students 'doing' science:

... planning opportunities which allow them to be investigators and to have hands on, asking questions and then seeking answers, trialling things, bringing in materials for them to actually use, asking them how can we do a fair test? How can we try this out? How can we actually validate that response? Is it real? How can we find that out? That's the sort of science [I do]. (T3/1/22/5)

To support her inquiry approach, T3 incorporated several ways to encourage questions. Students were immersed in stimulating activities during which they noted their questions. Positive affirmation created a climate where questioning was welcomed and expected: “Who would like to share one of their questions or their thoughts, their wonderings? Thanks, [name]...What is the white stuff in a kidney? Good question.” (T3/LT/14/5). T3 wondered aloud about possible investigations: “It was an idea I had. I thought maybe we could look and see how much lung capacity our boys had [compared with girls]” (T3/LT/27/5). She contested theories as described in Section 6.2.5.1 (p. 157). Although part of her general inquiry approach, developing questions about the natural world afforded students an important learning opportunity for science.

T3 displayed important PCK concerning health and safety. Ensuring each student used fresh cardboard as a mouthpiece to blow into the hose for the lung capacity experiment and providing gloves for handling animal organs showed T3 knew to consider safety issues inherent in science activities.

T3’s knowledge of science instructional strategies included use of demonstrations, representations and models, and activities that work. Demonstrations included informal dissections of animal organs in group or class situations: “So this is the animal’s windpipe and you can see really clearly that it goes into where? What happens to it?” (T3/LT/21/5). She demonstrated inflation of the lungs via the trachea and showed the passage of blood vessels from the heart to the lung and back by inserting a pencil. T3 also used demonstrations syntactically, for example showing the benefit of averaging multiple measurements.

Teacher explanations were not used as a strategy, but were co-constructed as above or developed by students, as in the sweaty hand investigations. Students also individually produced formal reports from their information gathering that explained their understanding of the structure and function of the heart and lungs.

While T3 used representations and models as an instructional strategy, she did not use them directly to convey science ideas to students: she supported students to use them as communication tools to present their own explanations developed from information gathering and observations. T3 facilitated use of diagrams by listing co-constructed steps involved in interpreting them and identifying their key features (FN/30/4). In pairs students made models of the heart and lungs from instructions photocopied directly from resource books, an example of an activity that works

(Appleton, 2002). T3 added to the activity by requiring students to annotate their models, labelling and explaining the function of the parts using information they had gathered from observations, books and the internet.

Several of the activities used at the beginning of the unit were also activities that work, photocopied from books. T3 included extra questions or investigations, such as adding a comparison between resting and exercise to the sweaty hand activity.

Use of scientific discourse types occurred incidentally rather than as a planned strategy. There were two examples of scientific conjectural argument. The reason for the position of the heart was debated, as described in Section 6.2.1.2 (p. 145), and a student question provoked debate as to why people might or might not be able live with only one lung. These debates were facilitated through use of interactive dialogue. The sense of joint enterprise also contributed; students and teacher talked together to further their joint understanding, putting up for discussion ideas they had read and evidence from observations.

A range of syntactic knowledge, including observational drawing, accurate recording of observations, data interpretation and investigation planning, was included in learning experiences. T3 made scientific values such as rigour, accuracy and validity explicit. She used her general pedagogical knowledge rather than specific science PCK in teaching these aspects. To teach observational drawing, she co-constructed with students a set of the key features of scientific diagrams. These key features were used by groups of students to critique a given set of drawings, then to improve their own. This structuring of direct interactions, a sociocultural teaching strategy, began with drawing fruit before moving to the less familiar animal organs. This strategy was observed with report writing for English, using a science context, so does not appear to be a science specific strategy. T3 deliberately planned a lesson on interpreting data that included strategies of co-construction supported by discussion in pairs (think pair share), and structuring of direct interactions:

Think pair share: why are we focussing on breaking an investigation down like this?

Recap on the two lots of data we have collected as a class (lung capacity and heart rates before and after exercise)

Think pair share: what might our data tell us? Record ideas on white board

Display A3 version of lung capacity data:

How is this information arranged?

How might we use it?

What might we find out?...

Each group will be given a different set of data to comment on. (Lesson plan/FN/23/6)

Staged tasks were used to focus students on accurate observation and recording as well as on planning their fitness investigations (Section 6.2.1.2, p. 145).

Syntactic teaching was not always planned ahead. As opportunities arose T3 used discussion to make scientific values explicit:

T3: So a scientist is like a forensic detective in what ways?

S1: They have to notice small changes...

T3: Right. They've got to notice the smallest differences....Fantastic [S2]: the smallest detail *can* be the most important....So hopefully, when I look at your written observations, I'm going to see some of those smaller details recorded this time. (LT/25/5)

Again, class discussion was T3's common general pedagogical practice, rather than syntactic PCK.

T3 demonstrated knowledge of dimensions to assess in science. Syntactic learning was seen as a key dimension, usefully informing both immediate and later teaching:

How can we develop ways to assess children's investigative skills? How can we assess students' questioning skills in relation to science? When we think of our students and their learning as part of this last science focus what do we need to consider when planning for science next term? Next year? (Science Investigations in the Senior School, document prepared by T3 for consideration by staff, 2006/FN/30/4)

Syntactic learning assessed in the observed unit included observational drawing skills and planning and reporting on scientific investigations. Indicators from the *Science Exemplar Matrices* (MOE, 2004) guided summative assessment with regard to "processing and interpreting data," "evaluating the investigative process," and "reporting" on scientific investigations (Assessment form/FN/29/6). The substantive learning that was assessed concerned the structure and function of the heart and lungs. T3 utilised a range of informal formative assessment strategies including observation, class discussion, self and group assessment. None of these are science specific tools. Formal pre- and post-unit written assessments used ARB tasks, which are specifically designed for science.

The final category of PCK is knowledge of students' difficulties and pre-conceptions. T3 expressed two common difficulties. Firstly she anticipated that students would not recognise their prior science experience because of "some interesting ideas about what is science. They really think you've got to have bunsens, because if you

look at what's in American sit-coms... they have kids in science labs...we don't have all that stuff here" (T3/I/8/5). The other was "getting them to realise that some words are used in different ways in a science context...like 'cell'...especially ESL students" (T3/I/22/5). T3 identified Class 3's prior science knowledge as the unit progressed through observation and marking: "What I realised was that lots of my year sevens hadn't actually done any scientific recording of investigations or if they had, it was very scant (T3/I/8/5); "...I guess I hadn't realised that for many of them, it [data interpretation] was really uncharted and new waters" (T3/I/17/7).

The evidence presented above suggests that T3 mostly drew on general pedagogical knowledge to teach science ideas rather employing specific PCK, suggesting that such knowledge is useful in implementing a new topic. The use of activities from books, activities that work, would also be expected in a new topic. Her addition of extra features, particularly extending them into longer investigations, suggests use of T3's PCK, but also reflected her strong belief in students participating in science investigation, a part of her sociocultural approach and orientation to teaching science that afforded many syntactic science learning opportunities. Beliefs about the science dimensions useful for assessment appeared an established part of T3's PCK, and meant assessment focused on development of both syntactic and substantive knowledge.

6.2.8 Summary of teacher knowledges evident in the unit

T3's science teaching in the observed unit involved contributions from each of the teacher knowledge domains. T3's general pedagogical knowledge was a significant influence on the nature of science learning opportunities afforded to students. Use of multiple discourse types encouraged participation, facilitated informal assessment and promoted student accountability. Contextual, curriculum and science content knowledge determined the topic and content covered. Educational aims and beliefs about learning influenced the nature of learning opportunities and content. Of particular significance was T3's syntactic science content knowledge which enabled identification of opportunities to learn about science. Her sociocultural approach was important, firstly with respect to the breadth of distributed cognition available in her classroom. Had she not encouraged so much student participation and engaged them in building ideas from 'natural world' objects and investigations, many science learning opportunities would not have arisen. Secondly, her belief that students learn about science by doing science, a participatory notion, was pivotal: students' scientific practices were visible, enabling T3 to use her syntactic knowledge to identify and address strengths and gaps and make scientific values and practices explicit.

The development of T3's knowledge useful for science is addressed next.

6.3 Development of teacher knowledge

Knowledge from three domains appeared critical to the opportunities for science learning afforded in this unit: T3's sociocultural teaching approach, an aspect of general pedagogical knowledge, her science content knowledge, both syntactic and substantive, and her PCK, in particular her orientation to teaching science. Development of this knowledge is discussed here. Finally, development of T3's PCK was observed during the unit. The process is described at the end of this section.

The elements of T3's sociocultural practice that afforded most opportunity for science were participation in authentic activities, and widely distributed cognition. T3's view of students as participants in a discipline seemed her usual approach: as stated earlier, she was overheard referring not only to her 'scientists' but to her 'writers' and 'mathematicians' (FN/21/5). Participatory notions linked with her belief that a purpose of education was to introduce disciplines as potential careers, (Section 6.2.2, p. 153). T3 attributed her participatory approach to her daughter's science experience in Years 7 and 8: "I want it [science] to be much more than what my daughter got...which was a lot of copying from the whiteboard" (T3/I/8/5). Perceptions that practical experience enhanced learning contributed to her approach (Section 6.2.3, p. 154).

The benefits that T3 had seen as students engaged in investigations during science units taught previously meant she actively looked for these opportunities when considering contexts for science. She had a history of investigating the natural world with her students: "a number of years ago, we did composting and decomposition... we had things rotting all over the place... we did some dyeing last year and we tried to do natural dyes" (T3/I/22/5). These choices indicate that T3 was confident in investigating the natural world along with her students and showed persistence in doing so:

Our first experiments were total disasters...we'd done some research about how we might be able to do it and we were trying to use natural products as dyes and it didn't work that well...but we went back to the drawing board, I talked about it with my colleagues and we tried different ways and then we did it again. (T3/I/22/5)

Reflection on the opportunities inherent in these investigations reinforced for her their value for learning: "I think it is useful for them to think about how to go about setting out doing an investigation...What will they have to do if they really want to

find the answers?" (T3/I/22/5). She described her learning about use of investigations developed as a result of teaching: "I didn't ever do any of these sorts of investigation when I was at school, even when I got up to seventh form. So I guess it's been developed in my own teaching job" (T3/I/17/7). Professional development undertaken to support her general inquiry learning approach immediately preceding the unit encouraged her: "It was about authentic inquiry...I came away...reflected on my class description...and I thought, 'I'm going to do fitness and the human body'...I saw there was potential for them to set up investigations..." (T3/I/8/5). Opportunity for student investigation was a critical factor in her choice. Knowing to critique possible contexts for opportunities for authentic investigation could be considered useful science PCK.

Personal reflection supported T3's continued use of natural objects, for example animal organs, which contributed to the widely distributed cognition observed: "They were really helpful...I could blow through the trachea and they [students] could see and hear" (T3/I/17/7). Reflection on the benefits she saw for student engagement reinforced her belief in natural objects as a tool for cognition: "I've always thought it's really important that we get them doing hands-on type things and I think that [students' responses] just further cements my views on it" (T3/I/17/7). Use of widely distributed cognition through co-construction and group work had become T3's normal practice, supported by her beliefs about the importance of discussion for learning (Section 6.2.3, p. 154): "I do a lot of group work, full stop. I don't just wait until science to do it" (T3/I/17/7). Use of computers and books to answer students' questions was part of an inquiry approach.

T3's syntactic science content knowledge underpinned the many opportunities observed for students to learn about the nature of science. Having her students investigate at school where she could observe them was important in prompting use of this knowledge. Appropriate scientific practice was often made obvious for T3 by its absence and was then addressed, for example presenting data as the findings of an investigation: "they [students] weren't *interpreting* the data" (T3/I/17/7). Investigating with her students meant her personal scientific thinking could be shared as it occurred, for example, the surmising about the colour of fresh blood as described in Section 6.2.1.2 (p. 145). Much of her syntactic knowledge appeared latent: it was background knowledge. For example, T3 displayed procedural knowledge concerning different ways to control investigations. When asked about its development she said she was just "aware about having controls: if you're going to test this, you have to keep some things consistent and change others and if you're going to test a theory out, you need to have another group to make a comparison to"

(T3/I/29/7). Goldsworthy et al.'s (1998) discussion of fairness in relation to biological investigations, an article familiar to T3, may have been influential here, but her school science background may also have helped establish such knowledge.

This topic was new for T3 so development of her substantive topic related knowledge was intentional. She felt a responsibility for “getting my head around the topic myself, being able to answer a few of their questions correctly!” and so “trolled the internet and I use You Tube if I can find things because you can show them things. I use TKI and ARBS if I can” (T3/I/22/5). Her knowledge of general concepts, the focus on structure and function of the heart and lungs closely aligned with expectations of the 1993 curriculum, suggesting a possible role in their development (Section 6.2.6, p.161). Key concepts that were set as a focus by the syndicate in the planning stages of the unit perhaps guided her reading and subsequent knowledge development. T3 said content decisions arose from “some of the questions [students] were asking at the time” and examining “what my kids told me they already knew, and thinking about ‘What did they need to know?’ in order to make some sense out about how the heart works and lungs work in order for us to do those fitness activities” (T3/I/29/7).

T3's general inquiry approach combined with her emphasis on practical and participatory experience to form her guided inquiry orientation to science teaching, which is part of PCK. T3 began to use an inquiry approach because of school-wide policy and embraced it, independently seeking and attending relevant professional development opportunities. Inquiry requires initial immersion in the context to develop student questions. Use of immersion had changed T3's science teaching: “[In the past] I would have saved the hearts until later on” (T3/I/18/5). Reflection on its effects convinced her of its value: “It's captured them, I think: they are quite keen: they can see the point” (T3/I/18/5). Reflection also improved the strategies she employed for developing questions: “I used to have a wonder wall but then I got a lot of dribble put up there...it was not on topic, by now putting it in their books, I think it's a bit better” (T3/I/18/5). Student questions afforded many science learning opportunities during the unit.

Development of other aspects of T3's PCK was facilitated by newness of the topic and her use of practical experiences, ‘doing science’ with her students. One general science PCK strategy, developed early in the unit, was optimising her time with students as they engaged in key practical experiences. The first practical session on the 14th May involved a circuit of six activities, five of which were investigations or

observations of organs. T3 found this was not effective: “[I was] thinking that we could move around a number of stations. In fact, they didn’t do some things particularly well so I had to retrace my steps...I guess I reflect on my next steps” (T3/I/22/5). Reflection led her in later lessons to base herself at one focus practical activity through which each group rotated in a circuit of otherwise independent, mostly written, tasks. This management strategy is valuable PCK for managing science learning opportunities, allowing teacher presence to support students’ management of a practical activity and facilitate socially mediated learning.

Development of topic specific PCK was observed when T3 applied the above strategy to explore the sheep pluck. She had not anticipated a heart coming attached to the lungs, so this teaching was unplanned. She helped groups identify the difference between the organs’ textures: “It’s really good now for us to be able to feel both and get a comparison” (T3/LT/21/5). In working with the first group she did not know exact locations of vessels, so picked up a pencil to probe their destinations. With later groups this became an intentional strategy. As a student prodded the heart some congealed blood moved into the aorta. This too became part of the lesson for other groups. Confidence and speed improved with each group: the first taking 27 minutes and the last 14. There was no compromise on what was included, just greater efficiency. Repetition of practical experience developed her PCK: learning what was useful to explore, how, where, and in which order.

Intentional PCK development was also evident. T3 and the other syndicate teachers tried out activities together before lessons. T3 regarded this practice as important in developing knowledge for teaching: “We had to actually play around with the lungs and do some of that inflating before we brought it into the classroom” (T3/I/22/5); “I don’t know what I thought they [lungs] were going to look like, but I didn’t think they were that large” (T3/I/17/7). T3’s contextual knowledge facilitated opportunities for PCK development. Organising syndicate teachers to take release days together enabled them to “divide up stuff amongst us; somebody will go off and search the [school] journals. Somebody will be doing the ARBs...then we come back and we share” (T3/I/22/5). T3’s PCK regarding science assessment also developed intentionally. She searched for assessment tools for investigation skills. Discussion with colleagues resulted in her locating the *Science Exemplar Matrices* (MOE, 2004), which she applied in assessing students’ investigation skills (Section 6.2.6, p. 161).

Intentional development of PCK included reading. T3 found activities such as the sweaty hand observation in classroom library books. She was able to show students 'heart strings' (chordae tendinae) in the sheep's heart as a result of reading; she was intrigued to find they actually existed (LT/21/5).

From examination of the above evidence, it appears that four processes contributed to the development of knowledge useful for science teaching in this case: 'doing science' with students, reflection, repetition of activities with different groups and intentional knowledge building. 'Doing science' with students enabled T3 to enact her syntactic knowledge and allowed spontaneous PCK development through repetition of activities with different groups. Reflection was an important part of this process as it changed or reinforced T3's science teaching practices. Intentional acts including reading, practising activities and discussing resources with other teachers facilitated development of both substantive knowledge and PCK.

6.4 Student perceptions of learning

The final research question for this study concerned the influence of teacher knowledge on students' perceptions of their learning. This section presents an analysis of students' responses from questionnaires and interviews. Student questionnaires and focus student interviews were analysed as described in Section 3.6. The analysis of questionnaires is presented in Section 6.4.1 and that of focus student interviews in Section 6.4.2.

6.4.1 Whole class questionnaires

All 30 students completed questionnaires after completing the fitness unit. The analysis of student questionnaires is presented here.

6.4.1.1 *Utility and enjoyment*

Responses about overall enjoyment and utility of the unit are shown in Figure 6.3. Responses for utility are more strongly positive than those for enjoyment.

Figure 6.3: Responses to student questionnaire, Q.11 and 12: Utility and enjoyment

Q.6 asked students to write what they most enjoyed about the unit. Two activities were most commonly identified: exploring organs (14) and making models (12). Other aspects enjoyed were: investigations (3); measuring lung capacity (3); learning about the body (2); doing new things (2). Individuals enjoyed the topic of fitness, statistical analysis, drawing diagrams, working with others and taking their pulse. Six students said there was nothing they did not like. Nine students disliked working with animal organs. Aspects that individuals disliked were: sheetwork; how to take a pulse; fitness; fitness investigations; highlighting information; 'repeating things because people didn't listen'; working in groups for investigations. One student found the unit a "bit boring" and one disliked "mainly everything" because they "hate science".

The following pairs of graphs explore students' perceptions of enjoyment and utility for learning of given activities. Figures 6.4 and 6.5 show responses to the exploration of fresh animal organs and other activities comprising the immersion phase of the unit. Examination of the connected heart and lungs is included here, although it occurred later in the unit.

Figure 6.4: Responses to student questionnaire, Q.8 Part 1: Student enjoyment of fitness unit activities

Figure 6.5: Responses to student questionnaire, Q.8 Part 1: Student perceptions of utility for learning of fitness unit activities

Immersion activities were seen as only moderately enjoyable and useful for learning. The exception was measuring lung capacity, which was the most popular activity, although fewer viewed it as useful for learning. Examining the connected heart and lungs was seen as enjoyable and useful for learning by more students than other activities exploring organs. This activity occurred later in the unit and, unlike the immersion activities, students completed this exploration with the teacher present, facilitating discussion about structure and function. Immersion activities were largely independent and focused on accurate drawing of organs rather than structure and function (see Appendix O). Responses to activities involving organs revealed a gender bias in the distribution, shown in Figures 6.6 and 6.7. Only one negative response was from a male. There was a slight positive shift for the activity using organs that occurred later in the unit. The four girls consistent in disliking activities involving real organs also consistently viewed them negatively with regard to utility for learning.

Figure 6.6: Analysis by gender of enjoyment of immersion activities involving fresh animal organs

Figure 6.7: Analysis by gender of enjoyment of later activity involving heart and lungs

Figures 6.8 and 6.9 show responses to activities that did not engage students directly with natural objects.

Figure 6.8: Responses to student questionnaire, Q.8 Part 2: Student enjoyment of fitness unit activities

Figure 6.9: Responses to student questionnaire, Q.8 Part 2: Student perceptions of utility for learning of fitness unit activities

The first two activities represented in these graphs were the same activity used diagnostically initially (far left) then later, summatively; more students found the former useful. The two model making experiences were enjoyed by a large proportion of the students. Many also perceived them to be useful for their learning. More students regarded other activities in this set as valuable for learning than enjoyable. These activities focused mainly on structure and function of the heart and lungs. The response pattern suggests that students largely perceived learning in science as substantive and that they saw this knowledge as largely acquired through reading, modelling and listening. Responses to the exploration of heart and lungs, in Figures 6.4 and 6.5, suggest that students saw value in investigating real objects when used to develop substantive knowledge.

Figures 6.10 and 6.11 show responses to experiences focused on developing skills for scientific investigation, including student planned investigations.

Figure 6.10: Responses to student questionnaire, Q.8 Part 3: Student enjoyment of fitness unit activities

Figure 6.11: Responses to student questionnaire, Q.8 Part 2: Student perceptions of utility for learning of fitness unit activities

Responses suggest that students saw investigations they planned and carried out as more enjoyable and useful for their learning than activities designed to practise specific scientific skills. Student investigations directly explored aspects of fitness, so issues of perceived relevance may also have been of consequence. Responses for utility were less positive than those for activities focused on substantive knowledge (Figure 6.9), supporting the interpretation that students viewed learning substantive knowledge as more valuable than learning investigative skills. Student comments in the school newsletter also supported findings that they valued substantive knowledge development:

Science has been awesome so far...We've learnt there are four chambers to the heart...When I watched Health, I knew what they were talking about. They were talking about ventricles and I knew our heart had two....I've learnt in Science that there is blood with oxygen that gets pumped around the body and blood that needs oxygen gets pumped to the lungs to get oxygen.
(School newsletter/FN/27/5)

6.4.1.2 Perceptions of learning

Analysis of responses to Q.1 showed that most students (28) identified new or interesting learning as pertaining to organs. Responses were general: “about” the heart and/or lungs; “where” organs are; “how” organs work; “naming” or “labelling” parts. Several students identified an *activity* as learning, responding with: models (7); measuring lung capacity (6); fitness surveys (6); organ dissection (5); taking their pulse (4); internet research (1); and blowing into lungs (1). Some identified empirical observations, for example: “blood jellifies over time” and “Year 6s have a high resting pulse”.

Analysis of responses to Q.3 suggested the majority of students believed their teacher's intention was for them to learn about organs: 19 responses identified name and/or location of organs; 14 responses included organ function, several specifying the role of the heart and lungs in pumping oxygenated blood around the body; one response included the appearance of organs. Only six responses identified syntactic aspects among perceptions of teacher intentions for learning: interpreting numerical data (2), planning an investigation (2), “doing things in a scientific way” (1), and “what science is” (1). Three students identified knowing about fitness and staying healthy. One student identified “working well as part of a group”. One student believed T3's goal was for students to learn to gather information from books and the internet.

Figures 6.12 and 6.13 show that when provided with a list of substantive ideas and investigative skills covered in the unit, most students reported improved or high levels of understanding for each area. Figure 6.12 shows responses for substantive ideas; Figure 6.13 shows responses for syntactic aspects of science covered in the unit.

Figure 6.12: Responses to student questionnaire, Q.10: Student perceptions of learning given ideas/skills (Part 1)

Figure 6.13: Responses to student questionnaire, Q.10: Student perceptions of learning given ideas/skills (Part 2)

Most students indicated they felt they developed a moderate understanding of syntactic aspects of science from the unit; students were more positive about their understanding of substantive aspects. Substantive gains reported by students reflect opportunities for their development. Heart structure and function were studied first and with more support than was given to the lungs. Little attention was given to other organs. Considerable time and attention was also given to developing syntactic knowledge. Appendix O shows several lessons focused deliberately on accurate recording of observations, planning investigations and analysis of data, for example. Requirements for planning an investigation were the subject of student group and personal reflection as well as a focus for summative assessment toward the end of the unit. Despite this emphasis in teaching, more students used the 'understand this a bit better' category for learning gains for syntactic learning. This may be because such learning is less easy to define for students or use of moderate categories provided a 'fallback' position for students uncertain about quantifying their learning. Syntactic learning is ongoing in nature and less likely to be perceived as 'new learning': more students indicated they already knew a lot about syntactic aspects. It may be more difficult for students to recognise incremental advances in pre-existing skills or values than in clearly new substantive knowledge. Comparing the responses to Q.10 with those to Q.3, where few students identified syntactic aspects as being among T3's intentions for their learning, may indicate that students saw T3's aims for learning as focused on the substantive aspects of the topic and therefore focused their own attention on these aspects creating greater perceived knowledge gains in these areas. Responses to Q. 10 also reflect the interpretation suggested in Section 6.4.1.1 that students valued and attended to substantive science learning more than they did syntactic aspects.

6.4.1.3 Perceptions of teacher effectiveness

Ten students thought T3 'very effective', 16 'quite effective' in teaching the unit and four rated her 'ok'. Students felt she was effective because she was helpful, ensured they understood, explained clearly, and provided different ways to learn.

The following graphs show students' perceptions of the utility of specific teacher actions for their learning. Figure 6.14 includes actions regarding development of science ideas and skills. Figure 6.15 includes actions regarding feedback, reflection and goal setting. Figure 6.16 includes actions regarding student accountability and management.

Note: The vertical axis indicates the number of responses

Figure 6.14: Responses to student questionnaire, Q.9: Student perceptions of utility for learning of teacher actions regarding development of science ideas and skills

More students saw teacher actions as very useful in situations where the teacher was obviously guiding the learning (first four actions on the left of Figure 6.14). Less positive categories were used about apparently student led development of ideas.

Responses to the next set of teacher actions regarding accountability and management (shown in Figure 6.15) support the pattern described above: teacher feedback was valued highly by more students than personal reflection and peer feedback, which were more commonly rated as 'quite useful' for learning. The other aspect valued highly by more students related to substantive knowledge: filling out 'what I know' sheets about heart and lung structure and function. An activity reflecting on the contribution different types of investigation made to learning was valued by many students, but also seen as 'not useful' by the largest number (6).

Note: The vertical axis indicates the number of responses

Figure 6.15: Responses to student questionnaire, Q.9: Student perceptions of utility for learning of teacher actions regarding feedback, reflection and goal setting

Note: The vertical axis indicates the number of responses

Figure 6.16: Responses to student questionnaire, Q.9: Student perceptions of utility for learning of teacher actions regarding accountability and management

Teacher actions managing behaviour and student accountability were viewed as 'quite useful' by the majority of students. Responses concerning management of groups showed more students felt working with groupings of their own choice assisted learning, and most student valued highly T3 ensuring that each group covered all the tasks.

Overall, more students saw greater utility in actions in which the teacher was overtly leading and managing learning, and less perceived actions involving personal and peer contributions and reflections as useful for learning, suggesting a general perception that teacher knowledge and views were more trustworthy than their own. Most students believed T3's actions facilitated their learning to some degree.

6.4.2 Focus student interviews

This section analyses data from interviews with four focus students in Class 3. Details of students selected by T3 for interviews are provided in Table 6.1.

Table 6.1: Case 3 Focus Students

Student	C3FS1	C3FS2	C3FS3	C3FS4
Year	8	8	7	8
Gender	Male	Male	Female	Female
Ethnicity	NZ European	Pacific Island (NZ)	Māori	NZ European
Interest in science	High	Moderate	Moderate	Moderate
Time at School 3	8 Years	8 years	7 years	8 Years

C3FS1 said he enjoyed science, read widely, watched science related television programmes and discussed the science that was happening at school at home. He enjoyed the fitness topic: "What happens inside your body, I really love that...finding out new things" (C3FS1/I/22/6). In class C3FS1 usually engaged actively in experiences and contributed frequently to class discussions.

C3FS2 said he enjoyed science at school but did no science at home and did not talk much about science, although he said his mother had a science degree. He enjoyed a television programme that used scientific methods to disprove common myths. He felt it important to do science at school in case students wanted to do more later. He was very positive about the unit topic, especially exploring the organs, but also felt he learned a lot from talking with other students and from reading. In observations, C3FS2 engaged well initially, and, although easily distracted, he usually completed tasks.

C3FS3 wanted to be a doctor so felt that paying attention in science was important. She said she sometimes did experiments from a book at home and her family had medical backgrounds but did not discuss science much. She enjoyed science at school because of the nature of the activities "like seeing how the organs and things work" (C3FS3/I/4/6). She felt science "helps you know more" and it was important to "know how your body works" in case "you wanted to be a doctor" and to "know how to do experiments" although no purpose could be given for the latter (C3FS3/I/9/6). From observations, C3FS3 usually engaged well with tasks, although sometimes lost focus on longer activities.

C3FS4 saw science as one of the more enjoyable subjects at school because "it's hands on and you're finding things out. You're learning stuff by interacting...I like finding things out, like making predictions and then getting them completely different and stuff like that... I like to find new things out" (C3FS4/I/4/6). She said she sometimes experimented at home and enjoyed wild life programmes and the "myth-busting" programme because "they show you things in slow motion and they do experiments" (C3FS4/I/4/6). C3FS4 was usually highly engaged on observed tasks, although she did not enjoy working with real organs and sometimes preferred to work independently rather than with a group. She actively contributed to class discussions, raising questions and sharing ideas.

6.4.2.1 Perceptions of learning

The responses of focus students concerning perceptions of their learning are summarised in Appendix Q. While C3FS2 and C3FS3 felt they worked hardest on group fitness investigations, C3FS1 put most energy into finding out about lung function. C3FS4 worked hardest on presenting the findings of the numerical analysis of lung capacity data. Reasons given for commitment all related to enjoyment and interest. C3FS1 linked his interest with complexity and new understanding:

I won't say because they're more complex, because everything's really quite complex, but I find the way they [the lungs] work more interesting [than the heart], because I truly believed at the start was that they were big, hollow bags and now I know they're like sort of solid with little tubes in...the air goes through the bronchial trees, into the air sacs, the alveoli, and that's where it absorbs in the oxygen through the capillaries around it...it's an absorbing and swapping around of stuff. (C3FS1/I/10/8)

Perceived important learning from focus students was almost entirely substantive, concerning heart or lung structure and functions, except for C3FS4 who felt position of body parts and taking her own pulse was important learning. She also valued substantive knowledge gains:

I enjoyed learning about my lungs and heart because I thought it was a bit of a mystery. Like, I knew some things about them but I never knew they had like, atrium, ventricles and all of that...you know it's there but you don't know how it works so it's cool to know how they work. (C3FS4/I/3/8)

All four focus students explained that the heart pumped oxygenated blood around the body. C3FS1, C3FS3 and C3FS4 demonstrated detailed understanding of circulatory functions. For C3FS1 and C3FS4 this included the role of the lungs in absorbing oxygen into the blood. C3FS2 included observed knowledge about size and position of lungs. Confusions concerning the role of the heart and/or lungs were exhibited by C3FS2 and C3FS3: C3FS2 believed that oxygen was needed to assist breathing and C3FS3 was not sure of the role of the lungs. The reason for the body's need for oxygen was not made explicit in teaching. All four students recognised oxygenated blood was important, but none explained why. It was clear that students identified and valued gains in substantive knowledge. C3FS3 said the unit had made her want to be a doctor more because "I know more about the stuff" (C3FS3/I/3/8). C3FS4's perception of learning was substantive also:

I know more about like, the heart, the lungs, the blood and air and like how [blood] goes around your body. I definitely know... a lot more about the things that relate to the heart and lung...I like just finding out new things and exploring different things...I just like knowing facts. I like knowing different facts. (C3FS4/I/3/8)

When asked if they had learnt to *do* anything new relating to science, C3FS1 suggested several syntactic aspects, including analysing and presenting interpretations of numerical data and the need for rigorous detailed observation: “I’ve learnt to notice things that are quite tiny, that may not look important but are” (C3FS1/I/22/6). He also identified elements of social learning such as organising a group and the benefit of working with people other than friends. C3FS3 identified using and analysing numerical data as new learning. C3FS4 identified gathering valid data through multiple collections: “like you have to get the pulse,... like find it, and you have to do it three times so you get the average” (C3FS4/I/3/8). Earlier, she had identified open mindedness as important in science: “because people go ‘I know everything about the heart: it’s just this muscle’ But then they don’t know nearly anything...You have to have an open mind to take it in” (C3FS4/I/4/6).

If it did not arise naturally in responses, the students were asked directly about their learning regarding syntactic aspects covered in the unit. Their comments clarify the suggestion in Section 6.4.1.2 (p. 181), that students have difficulty identifying syntactic knowledge gains. New syntactic knowledge was identifiable, as for C3FS1 and C3FS4 above, but gains in existing knowledge were less obvious. For instance, when asked about T3’s insistence that students design tables to record and organise data, C3FS3 said she “already knew most of it but that kind of rejigged my memory, I guess” (C3FS3/I 3/8). C3FS2 said “I’ve done it: I got taught it before” (C3FS2/I/29/7). C3FS4 commented on learning observation skills: “We’ve done it quite a lot of times in year four and five” (C3FS4/I/3/8). As in class questionnaires (Section 6.4.1.1, p. 174), students struggled to identify a specific purpose for syntactic learning, suggesting its utility may be in future schooling and possibly careers.

6.4.2.2 Supports for learning

All four students identified the importance of seeing and exploring the organs for their learning, suggesting they may have linked empiricism with science: “Science is about? Experimenting.” (C3FS2/I/4/6); “In science you’re finding things out and you have to see it for real.” (C3FS4/I/4/6); “It’s quite good having the real things up close, to see them and feel the texture” (C3FS3/I/3/8). Real things were “Not like pictures” because “you can see what it looks like, it’s texture and...what’s actually inside it: ‘actualness’” (C3FS1/I/14/5). Students’ comments aligned with T3’s belief that students learn through practical experience: “The thing about an experiment is it just shows you and you can see it; it just shows you how it works” (C3FS1/I/22/6). “You can see the muscles changing and which bits are like taking the most pressure...And how much my chest goes out when I breathe” (C3FS4/I/3/8).

Student comments in the school newsletter expressed similar ideas: “This has been a good way to learn about our bodies...Learning from a picture wouldn’t be the same...I loved the lungs. They were soft...I thought they were hollow but they weren’t” (School newsletter/FN/27/5). Such views display a naive understanding that scientific theories are directly apparent from evidence.

C3FS1 suggested that theory usefully informed observation: “when observing, you can only see a limited amount...but reading, you can actually describe things, [with] understanding, like I didn’t know what the alveoli were when I looked” (C3FS1/I/10/8). Combining reading with practical experience was seen as optimal for learning: “You find most of your information from reading and researching on the computer and internet” but exploring natural objects meant “you can see it and you can connect the facts to the thing...you need both to get a good ‘knowing’” (C3FS4/I/4/6). These views again support interpretations in Section 6.4.1 that students valued practical work more when it supported substantive learning.

Diagrams and models were similarly valued because they facilitated substantive knowledge development: “reading’s fun with diagrams...and we made those lungs and hearts. It was [helpful] because you see, actually, how [it works]: with the bottle, it shows what the diaphragm does and all that” (C3FS1/I/10/8).

With regard to supports for syntactic knowledge development, learning to observe detail was attributed by C3FS1 to it being made explicit by T3, enabled through participation: “Observing is very important. The teacher always goes on and on... Like, she said ‘Notice’. ‘Can you find...’, or ‘Notice’, and then I just learned to do that automatically” (C3FS1/I/22/6). Learning about investigation occurred through participation for C3FS4 also, along with reflection and feedback:

I think you learn to do investigation by the end product, to see how well you did and have it all laid out in a sheet and you can really tell what you did right and what you did wrong and what you need to work on and everything...because you can really build on it [teacher feedback] and look back and say, ‘Ohh, well I won’t do this because last time that turned out really bad. I’ll do this because that was really good.’ (C3FS4/I/3/8)

Student comments showed that they valued T3’s teaching approaches. Several students mentioned opportunities for peer and class discussion as helpful because it gave access to others’ ideas: “it’s like a small community” (C3FS1/I/10/8). C3FS1 appreciated T3’s provision of real organs, diagrams and the speaker. Other students also appreciated T3’s use of distributed cognition: “Instead of telling us what’s happening, she makes us find out what’s happening by what we see and stuff, I

guess if we find out, it probably makes us remember better than if she's just telling us" (C3FS3/I/3/8); "We could do it instead of the teacher" (C3FS2/I/29/7). Use of interactive dialogue was also identified as helpful: "She sort of circulates and then, like if we've done something, then she'll ask us more questions and keep us wondering" (C3FS4/I/3/8).

To summarise, interviews with the focus students suggest they applied themselves most to activities of interest to them. Substantive knowledge gains were readily identified and valued highly. New syntactic knowledge was identified, but gains in existing syntactic knowledge were less easily identified. T3's ability to make syntactic aspects explicit was seen to contribute to student development of syntactic knowledge, although participation in investigation, and associated teacher feedback and reflection were valued for this purpose also. T3's sociocultural approach was recognised as useful for learning by these students, especially her incorporation of widely distributed cognition, in that it provided learning opportunities from natural objects, symbolic and technological tools, and other students.

6.5 Summary

While T3 employed knowledge from each of the domains of the teacher knowledge framework in implementing this unit, her general pedagogical knowledge played a significant role because of the opportunities for science learning afforded by her sociocultural approach. Varied communicative approaches enabled co-construction of features of scientific processes and texts and made scientific values explicit, but also set firm expectations that promoted scientific rigour and completion of science tasks. Beliefs about the purpose of education meant T3 implemented science that was intended to build students' perceptions about the discipline and so incorporated a range of authentic activities. Strong beliefs about the value of practical experience for learning afforded students multiple opportunities to investigate the natural world which enabled T3 to draw on her syntactic knowledge and emphasise the nature of scientific practice and values.

The study of fitness was a new topic for T3. Four processes appeared to contribute to development of knowledge used in implementing the science unit: engaging students in practical science investigation; reflection; repeated use of the same activity with different groups; and intentional knowledge building through reading, searching the internet, and working with colleagues.

T3 employed a strongly sociocultural approach to the teaching of the fitness unit. The most significant contributions for science included students' participation in a variety of scientific investigations where adoption of scientific practices and values was encouraged. Widely distributed cognition was important for science; use of group and class discussion, the internet, a range of scientific texts and diagrams and natural objects all provided opportunities to engage with science ideas, vocabulary, text, processes and values.

Students in Class 3 readily identified and valued substantive learning about heart and lung structure and function. Students did not perceive syntactic learning as new and appeared not to value this type of learning opportunity as highly as those developing substantive learning.

Case 3 adds usefully to findings from the previous cases as both syntactic and substantive aspects of science were intentionally addressed. Examining the research questions in this situation has therefore contributed usefully to the larger study. In the next chapter the findings from all three cases are considered together; commonalities, comparisons and differences between findings from individual cases are identified in response to the research questions.

CHAPTER 7

Cross Case Analysis

7.1 Introduction

The previous chapters have described the nature of individual cases. This chapter investigates and discusses the aspects studied across all three cases identifying common themes and drawing on findings from individual cases to add to the overall understanding of the phenomena forming the focus of this study: the nature and development of teacher knowledge for science, the degree to which sociocultural approaches were implemented, and students' perceptions of their learning.

7.2 The nature of teacher knowledge

The details of the knowledge each teacher brought to their science teaching have been presented in Section 2 of Chapters 4-6. Table 7.1 presents a summary of the knowledge exhibited in each case study. In all three cases, knowledge from each domain contributed to the facilitation of science learning.

Table 7.1: Summary of knowledge exhibited by teachers in each case study

Knowledge Domain	T1 Rocky Shore Unit	T2 Science Fair Investigations Unit	T3 Fitness Inquiry Unit
Knowledge and beliefs about general aims and purposes of education and assessment	<ul style="list-style-type: none"> wanted students to develop skills and attitudes for independent learning to be prepared for secondary school linked independence with ability to use technology to locate information used assessment to inform next teaching and feedback to students and show progress assessed substantive knowledge for these purposes 	<ul style="list-style-type: none"> aimed to prepare students well for secondary school and raise awareness of potential careers wanted students to think critically about the world around them believed this could be achieved through learning to investigate using fair testing used assessment of student competency with processes to inform next teaching and feedback to students 	<ul style="list-style-type: none"> aim for students was to become independent and self-managing learners with own interests believed a purpose of education was to introduce a range of disciplines that may spark interests or careers believed purpose of science education was to build students' perceptions of science preparation for secondary schooling was a consideration in the inclusion of some activities assessed students' scientific practices, knowledge and general learning skills which informed next teaching, feedback and student goal setting believed assessment of syntactic aspects could improve science learning by informing school evaluation and review
Knowledge and beliefs about learning and learners	<ul style="list-style-type: none"> believed students built on existing knowledge negotiation of meaning through discussion was common in practice believed student interest and engagement were important prerequisites for learning believed practical work increased engagement believed students should maintain a written record of ideas to assist learning 	<ul style="list-style-type: none"> believed modelling and scaffolding were the most useful aspects of her practice for learning believed students learned through discussion used class discussion opportunities for informal assessment and evaluative feedback saw practical work as engaging and motivating. 	<ul style="list-style-type: none"> believed learning was enhanced by students answering their own questions believed students learned through practical experience saw participation in discussion and authentic practices as important for learning believed she facilitated learning by being enthusiastic and organised believed it was important to learn alongside students, but also ensure key points were covered; features observed in practice engaged students in reflection on their learning
Knowledge and beliefs about educational context	<ul style="list-style-type: none"> knowledge of school community, budgeting and governance meant staffing, equipment and books were available used Māori vocabulary to link everyday terminology with specialist vocabulary perception of students' interest in past topics influenced choice of topic knowledge of individual students' needs facilitated their inclusion in science meaning making 	<ul style="list-style-type: none"> knowledge of school and budgeting systems meant equipment and consumable materials were available knowledge of school organisation meant learning in other areas supported science understanding of parent community optimised their support for science knowledge of students, collectively and individually, informed effective management of groups and activities continual monitoring allowed targeted support and recognition of achievement 	<ul style="list-style-type: none"> knowledge of school's philosophy supported selection of and approach to topic awareness of New Zealand's bicultural context apparent in class routines. Organs handled in a culturally appropriate manner knowledge of school community facilitated supply of science materials knowledge of students influenced the choice of topic, meant individual needs were attended to and informed groupings to optimise learning monitoring of group work, regular marking and class discussion informed this knowledge

Knowledge Domain	T1 Rocky Shore Unit	T2 Science Fair Investigations Unit	T3 Fitness Inquiry Unit
General pedagogical knowledge and beliefs	<ul style="list-style-type: none"> • espoused and exhibited a social constructivist approach • created a sense of joint enterprise in the class • students contributed and developed ideas located during information gathering sessions using the internet and books • student contributions were valued • management of discussion facilitated student voicing of key ideas • used students' experiences, terminology and his personal stories to build vocabulary and conceptual understanding • structured students' direct interaction with representations through use of familiar contexts before transferring to less familiar contexts and more complex examples 	<ul style="list-style-type: none"> • used participation in authentic activities and staged approach • provided explicit criteria for each stage of science investigation • monitoring and feedback clarified expectations • enculturated students into scientific practices using highly structured direct interactions and everyday contexts • modelled each step followed by group and individual practice • group activities were common • authoritative classroom discussion limited ideas • examples of expert practice common but limited to own syntactic knowledge 	<ul style="list-style-type: none"> • sociocultural approach • student questions and ideas expected and valued, fostering a sense of joint enterprise • group work provided many opportunities for socially mediated learning • teacher led class discussions facilitated co-construction of features of scientific practice, texts and values • authoritative dialogue encouraged accountability for completion of tasks • staged tasks and structuring of students' direct interactions with scientific processes and texts made their nature explicit • widely distributed cognition: books, internet, natural objects and physiotherapist • students participated in discussion, authentic investigations, and used scientific communication tools to convey ideas
Curriculum knowledge and beliefs	<ul style="list-style-type: none"> • suggested integrating strands of curriculum were most important • planning and delivery focussed on the Living World contextual strand • little wider and horizontal curriculum exhibited • knowledge about prior coverage influenced selection of the topic • perceptions of vertical curriculum justified requiring accurate and tidy notes to be kept • knowledge of resources included curriculum support books and websites, where to get student resources and equipment 	<ul style="list-style-type: none"> • emphasis on fair testing, scientifically reasoned predictions and development of questions reflected emphases in curriculum • beliefs about vertical science curriculum also reflected the curriculum • horizontal curriculum knowledge supported science • used opportunities in science to address students' literacy needs • knowledge of resources included curriculum support books, and schools' scientific equipment 	<ul style="list-style-type: none"> • focus on behaviours that facilitated learning aligned with direction of curriculum • emphasis on syntactic as well as contextual science aspects aligned with curriculum • substantive content aligned more closely with superseded curriculum • believed her practical focus reflected the vertical curriculum • horizontal curriculum knowledge facilitated learning opportunities for science in conjunction with other learning areas • knowledge of resources included curriculum support materials, where to get student resources, everyday equipment and materials

Knowledge Domain	T1 Rocky Shore Unit	T2 Science Fair Investigations Unit	T3 Fitness Inquiry Unit
Science content knowledge and beliefs	<ul style="list-style-type: none"> believed science is a changing body of knowledge with change often resulting from improved technology stated that science is an empirically based process of knowledge generation that involves critical consideration of claims in classroom substantive knowledge from books and the internet was accepted uncritically as fact 'systems thinking' dominated substantive science knowledge knowledge of general concepts and principles included the Linnaean classification system, energy transfer through ecosystems, and adaptation to habitat topic specific content knowledge included: effects of the sun and moon's gravitational fields on tide patterns; names, characteristics and examples of the classes of rocky shore animals; examples of organisms from different trophic levels in a variety of contexts; complex energy relationships 	<ul style="list-style-type: none"> knew science investigation involves empirical testing and observation of the natural world believed: collegiality is important in scientific endeavour; useful scientific investigations develop from curiosity and wondering; science involves critical consideration of claims; scientific hypotheses are reasoned, cognisant of current scientific thinking and able to be tested; scientific data should be measured and recorded accurately and in an organised manner; and that validity of results is important in scientific endeavour knew that fair testing involves selection of an independent variable which is changed in ways allowing the effects of the change on the dependant variable to be measured, whilst other variables are controlled knowledge of other forms of investigation was not apparent limited substantive knowledge exhibited because of nature of unit: included factors that influence rates of reaction and properties and composition of milk 	<ul style="list-style-type: none"> syntactic knowledge included the need for rigour and accuracy in gathering and recording data believed that science must account for all natural occurrences, and science theories are contestable engaged students in many forms of scientific investigation modelled orderly recording of results knew how to control investigations knew that averaging multiple measurements, limiting the number of variables and increasing sample size would produce more reliable data importance of interpretation and theorising in science were recognised co-constructed with students a list of features of scientific investigations that included being planned, sharing ideas, working together and being flexible and adaptable knowledge of general concepts meant heart and lung structure and function were the focus in studying fitness knew an important principle was that the heart is a muscle that pumps oxygenated blood around the body topic specific knowledge developed included names, features, positions and functions of heart and lung structures
Science pedagogical content knowledge and beliefs	<ul style="list-style-type: none"> academic rigour orientation to science teaching emphasised development of scientific concepts included scientific representations in the form of models and diagrams used one activity that works conceptual development was sole focus for formal and informal assessment and monitored almost constantly using class discussion knew students would find the use of arrows in food chain diagrams difficult no science specific syntactic PCK was observed as no syntactic knowledge was explicitly taught 	<ul style="list-style-type: none"> process orientation to science teaching exhibited although indicated preference for teaching investigation skills within a context science instructional strategies included demonstration, explanation, and activities that work other strategies used to make syntactic knowledge explicit were part of general pedagogical knowledge, for example use of success criteria closely monitored student achievement of each stage of the investigation process using general assessment methods including class discussion, individual conferencing and marking of work knew that students struggled to develop relevant testable questions 	<ul style="list-style-type: none"> guided inquiry approach to science teaching involved students in investigations about fitness pertaining to their personal and school context knowledge of science instructional strategies included use of demonstrations, representations, models and activities that work supported students to use representations, models and explanations as tools for communicating their developing science ideas use of scientific discourse types occurred incidentally as a result of interactive dialogic communicative approach general pedagogical knowledge used to teach syntactic aspects: co-construction through discussion, structuring of direct interactions and staged tasks substantive and syntactic aspects formatively and summatively assessed informally using observation and discussion and formally using pre and post-unit, self and group assessments believed students have difficulty recognising class activities as science because of stereotypical views of science occurring in laboratories using technical equipment knew specialised use in science of common vocabulary could be problematic for students

The following discussion considers commonalities and differences within and across knowledge domains exhibited by the three teachers, and discusses the opportunities for science learning that occurred. The order in which the domains are discussed moves from the more general to those particularly focused on science.

7.2.1 Knowledge and beliefs about general aims, purposes and values of education and assessment

All three teachers claimed to have long-term educational aims for their students (Sections 4.5.2, 5.5.2, & 6.5.2). T1 and T3 said they wanted to develop independent learners; T2 wanted her students to be able think critically about the world around them. All three were conscious that they were preparing students for secondary school, although this was not a strong concern for T3. T3 and T2 held beliefs that one of the purposes of education was to introduce possible careers and saw science as providing such an opportunity.

There was an interaction between teachers' aims and the nature of their science teaching. T1 associated independence in learning with use of technology to locate information which he also suggested was an important support for secondary education. His students were engaged for long periods of time locating information about the rocky shore from books and the internet. T3 supported the development of independent learning by emphasising the learning of social content: learning how to learn. T2 believed that fair testing focused students' critical attention on the world around them and spent the science unit developing fair testing skills with her students. All three teachers used opportunities in science to build students' capacity to cope with secondary school. T1 encouraged tidy note keeping and skills for locating information in preparation for secondary school. T2 said she thought that students' familiarity with fair testing procedures would support their science development at secondary school. T3 said she included teaching about recording an investigation and scientific vocabulary to give students experience with these prior to secondary school. T3 raised the possibility of science as a career by highlighting the practices students were undertaking as 'science' and referring to them as 'scientists'.

All three teachers found opportunities within the teaching of science to assist students toward their educational aims. Their aims also influenced opportunities for science learning, sometimes in combination with other domains. T3's aim to build perceptions of science for her students appeared to impact on the nature of activities she provided, in conjunction with her beliefs about what science was, an

aspect of syntactic knowledge; practical activities and investigations were common. T2's beliefs about the significance of fair testing in vertical curriculum and in developing critical thinking contributed to making it the focus of her teaching. T1's belief that independence in learning meant using technology to locate information contributed to making science learning opportunities largely substantive. These beliefs connect strongly with, and may have contributed to, each teacher's orientation to teaching science, an aspect of PCK, which significantly influenced the nature of learning opportunities for science, as will be discussed in Section 7.2.7.

With regard to knowledge and beliefs about the purposes of assessment, all three teachers used assessment to inform next teaching and feedback to students. T1 used informal and formal diagnostic assessment of students' substantive ideas to inform his teaching. T2 monitored students' achievement with each step of the investigation process. T3 monitored development of both syntactic and substantive ideas. T1 identified gaps in understanding using formal and informal assessment that became the focus for information gathering and discussion. T2 and T3 introduced extra activities as a result of monitoring progress. T3's informal assessment and monitoring of student investigations raised new syntactic learning goals, such as improving students' ability to record accurate observations.

T1 used assessment of substantive ideas to show progress in science. T3 saw a purpose for assessment in informing school review and evaluation of science programmes, and believed syntactic aspects were useful for this purpose.

In each case as a result of assessment, additional opportunities for science were included to support students to achieve the intended and, in the case of T3, new, science learning goals. The focus for assessment and additional opportunities depended on the teachers' content knowledge and their orientation to teaching science.

7.2.2 Knowledge and beliefs about learning and learners

An examination of the evidence presented in Sections 4.2.3, 5.2.3 and 6.2.3 shows that the three teachers held some common beliefs about learning and how it occurs; however, their individually held beliefs seemed to influence the nature of opportunities provided for science learning.

All three teachers believed that practical work assisted learning because it was engaging and motivating and all three incorporated it in varying ways and degrees.

T1 and T3 also felt that seeing and handling real objects was important in developing understanding. T1 thought this was because all the senses were involved which promoted learning. T1 arranged a field trip that allowed students to experience and explore the nature of the rocky shore and its inhabitants. T3 made natural objects available to students in the form of animal organs and investigations about their own bodies and student fitness; students had multiple opportunities to investigate the natural world in a variety of ways. T2 claimed that the modelling and scaffolding she provided were the aspects of her practice most useful for learning. The three practical sessions provided in Case 2 correspondingly included teacher modelling and use of exemplars of scientific practice, often in the form of written criteria in providing opportunities to develop investigating skills. When T2's students eventually investigated their own questions for their science fair projects, it was as summative assessment.

In addition to beliefs described above about practical work, T3 indicated through her comments and practice that she saw participation in authentic activities as valuable for learning. Students in Case 3 explored organs, recorded observations, asked questions, used models and scientific reports to convey their substantive ideas, interpreted data and planned, carried out and reported on their own investigations of student fitness. Seeing the value of participation in authentic activities for learning contributed to T3's guided inquiry orientation to teaching science and underpinned her sociocultural approach. T1 expressed similar participatory beliefs about the importance of engaging in investigation of the natural world for learning and allowed students to freely explore the rocky shore on the field trip. This was the only opportunity provided for students to explore natural objects, perhaps because of the topic and setting: the rocky shore was physically distant from the school. However, there was little structured support for developing investigation or observation skills and the field trip was largely used to confirm and build on substantive ideas. T1's use of practical work connected with his academic rigour approach to teaching science, an aspect of PCK which views substantive understanding as the aim of science learning. Findings from all three cases therefore suggest that while views on the importance of practical work for learning meant that opportunities to engage in such tasks were provided, the influence of teachers' orientation to teaching science was significant in terms of the nature and purpose of these activities.

All three teachers suggested that student discussion contributed to learning. Class discussion was a feature in all three cases. T1 said that students built on their existing knowledge. In Case 1 diagnostic class discussion highlighted students'

existing ideas about the rocky shore that preceded students' information gathering. T1 managed dialogue to enable important syntactic ideas to be first stated by students. T3 used class discussion to co-construct features of scientific ideas, practices, texts and values with students. T1 and T3 commonly used an interactive dialogic communicative approach: students' ideas contributed to the development of scientific understanding. In Case 2 class dialogue, although interactive, was often authoritative or evaluative, and used to check how well students were achieving T2's expectations concerning scientific processes. While discussion in all three classes provided opportunities to share and clarify science practice or ideas, the discussion in Cases 1 and 3 supported an observed sense of joint enterprise and enhanced the widely distributed nature of cognition available in these cases. Science ideas beyond those of the teacher were available to students. The science related ideas available to students in Class 2 were essentially T2's. Thus, although all three teachers believed that discussion supported learning, they used it for different purposes and in different ways. In Case 2, authoritative discourse limited the range of science ideas that were introduced to those of the teacher, whereas interactive dialogic discussion in Cases 1 and 3 provided access to a broader range of scientific ideas.

Differences in teacher beliefs about learning appear to have resulted in differences in the nature of opportunities provided for science learning. T2's beliefs focused her practice on ways to convey her personal understanding of scientific processes to students. T1 and T3's beliefs and practice placed more importance on student involvement and supported a sense of joint enterprise where student ideas contributed to science learning opportunities. In all three cases the teacher's orientation to teaching science appeared to influence the nature and purpose of the practical and discussion opportunities they provided.

7.2.3 Knowledge and beliefs about educational context

While knowledge in each of the categories in this domain was observed, the categories that most influenced the science learning opportunities afforded by each case concerned knowledge of the school and knowledge of particular students (Sections 4.2.4, 5.2.4 and 6.2.4). However, knowledge of the New Zealand school system allowed T1 to employ an extra teacher, enabling him to focus on science with the Year 7 and 8 students.

Knowledge of the school community that afforded opportunities for science concerned knowledge of staff, school organisation, budgeting, and knowledge about

parents. T1's knowledge of staff confidence in different areas meant he arranged staffing so that he could support Year 7 and 8 students. For T2 and T3, knowledge of school organisation facilitated syndicate planning that supported science, through planning together (T3) and timely planning of English and mathematics to support science (T2). T1 and T2 managed school budgeting processes to purchase science equipment used during the unit. All three teachers accessed parent and community support for science. In Case 1 parents provided transport and support on the field trip. T2 used her prior experience to optimise parent support for their children's science fair project. T3 consulted parents over the use of animal organs and accessed equipment and expertise (a physiotherapist who spoke to students about muscles) from the school community.

Knowledge of the students as individuals in all three cases was supported by teachers' assessment practices. Knowledge of students assisted teachers' management of the class for science, for example by informing group composition or allowing them to identify students who could add useful ideas to class discussions. In all three cases, knowledge of students influenced the selection of the topic or the context of learning activities. Knowledge of individual students allowed all three teachers to support specific needs in science: a struggling reader in Case 1, students having difficulty identifying a question to investigate in Case 2, and addressing the needs of ESL students in Case 3.

Knowledge of New Zealand's bicultural context was not well applied in the science units observed. T1 used Māori terms for rocky shore animals in one lesson, although the purpose appeared more to link common and scientific names. No reference to Māori language or culture was observed in Case 2. T3 incorporated aspects of Māori cultural practice in class routines, but there was no deliberate attempt to do so in science apart from the cultural sensitivity she exhibited in the handling of fresh organs with her class, a reaction to the unease of a teacher in her syndicate who was Māori. Māori students would have found little representation of their culture in their experience of science in any of these cases. Similarly, non-Māori students had little opportunity to learn about Māori language and culture through science.

7.2.4 General pedagogical knowledge

This section draws together evidence presented in Sections 4.2.1, 5.2.1 and 6.2.1 to examine the opportunities provided for learning science through use of general pedagogical knowledge.

7.2.4.1 Teaching approaches

The teachers used their usual general pedagogical approaches to teach science content. Although evidence was limited, interviews with focus students and observations of teaching practice suggest that the teachers did not appear to employ a special approach to teach science. As differentiated in Section 2.3.2.1, T1 used a social constructivist approach although elements of sociocultural strategies were also apparent; T2 used a very structured staged sociocultural approach; T3 used a highly participatory sociocultural approach. Each teacher's approach, although different, afforded opportunities for science learning.

T1's social constructivist approach meant that he diagnosed, monitored and worked to address gaps in students' understanding. He engaged students in making meaning of substantive science knowledge relating to the rocky shore. Student ideas and questions created learning opportunities for science. That these learning opportunities were recognised as such and developed depended on the nature of T1's content knowledge, as did the emphasis on substantive science ideas that were the focus for science learning opportunities provided by his approach. The focus on development of substantive knowledge relates to T1's orientation to teaching science, part of PCK.

T2's approach, while classified as predominantly sociocultural, also contained elements of a developmental approach whereby the process of a fair testing investigation was broken down into its composite steps and achievement of each step practised. The focus on each step meant the nature of each stage of the process of a scientific investigation, although restricted to fair testing, was made very clear through T2's modelling and provision of clear expectations in the form of clearly specified criteria, a common feature of her general pedagogy. The nature of scientific investigation T2 made explicit was limited to her own understanding because of the narrowness of distributed cognition, as will be discussed in the next section. Restriction of science investigation to fair testing processes related to T2's syntactic and curriculum knowledge, as will be discussed in Sections 7.2.5 and 7.2.6. The focus on scientific process also relates to T2's process orientation to teaching science, part of her PCK.

T3's sociocultural approach was participatory in nature with a focus on authentic activities and practice. Students participated in authentic activities such as investigations of student fitness; they used scientific communication tools, such as diagrams and models, to convey their developing substantive science ideas. They

joined with T3 in identifying the key features of scientific practices such as observational drawing and investigations. Participation in authentic activities created opportunities for T3 to identify and address students' use of scientific practices and to make scientific values explicit. A further focus on learning social content through structured reflection afforded students opportunities to consider and improve the nature of their participation in science learning opportunities. The nature of the science opportunities provided by her approach, and the approach itself, relate closely to T3's guided inquiry orientation to teaching science, part of her PCK.

While each teacher's approach facilitated science learning opportunities, the content covered depended on aspects of each teacher's content knowledge. The nature of the content was also strongly associated with each teacher's orientation to teaching science.

7.2.4.2 Sociocultural approaches

This section describes use of sociocultural strategies as part of the general pedagogical knowledge domain, but the analysis presented also underpins considerations regarding the third research question, which is further discussed in Section 7.4. Analysis of sociocultural approaches was supported by the framework developed for this study (Table 3.4, p. 67). Use of sociocultural approaches afforded opportunities for science learning in all three cases.

Opportunities for socially mediated action were provided by all three teachers. Extensive monitoring and frequency of feedback in all three cases provided opportunities for active mediation of individual learning in science. In each case, group and class discussion provided opportunities for participatory construction of science knowledge, the nature of which depended on each teacher's orientation to teaching science. In Case 2, students carried out their investigations at home away from their teacher and other students, thus limiting opportunities for socially mediated action relating to development of science processes and values.

Cultural tools scaffolded learning in science in all three cases. In Classes 1 and 3, students accessed substantive ideas from a range of books and the internet. Class discussions in these cases enabled ideas found by groups or individuals to be made available to the class. Students in Class 2 were provided with written criteria for the steps involved in a fair test and other examples of expert practice in the form of completed investigation planning forms illustrating the fair testing process. These cultural tools were all created by T2, limiting the distribution of cognition, but they provided documentation of expected scientific practice that students could use as a

guide and measure for their independent scientific practice. In Case 3, the key features of cultural tools such as diagrams were identified through co-construction. Students then used these tools to present scientific information they had gathered, for example creating an annotated labelled diagram of the heart. Students had opportunities to learn to use some of the cultural communication tools of science, not just to understand the ideas they contained.

T3 used opportunities in science to focus students' attention on ways to learn when in group situations as well as how to function as a group, using structured reflection, co-construction of criteria for group behaviour and highlighting student examples of expert practice. Such a focus was not explicit in the other two cases. There is insufficient evidence to show whether or not such a focus on learning in a group increased opportunities for science learning. Student perceptions of the value for their learning of T3's use of structured reflection on group work were mixed.

Salomon and Perkins (1998) describe one further type of socially mediated action: the social entity as a learning system where the collective system learns as they interact together. While this type of interaction was not noted in cases during detailed analysis of data, on reflection it could perhaps have been occurring in an ongoing way in each class as the teacher and students or groups continued to work together. An example could be Class 2 quickly moving into group tasks, as this is a common practice in their classroom, or a group in Class 3 becoming more adept at working together to gather data on student fitness. This level of detail was not noted during observations so the occurrence of this type of learning and the science learning opportunities it offered in these cases is unknown.

Situated and participatory learning is another feature of sociocultural practice. Participation in authentic science activities was observed in Cases 2 and 3. In Case 1, exploring at the rocky shore could be considered authentic scientific practice and students may have engaged in classification at this time; however, such opportunity was unstructured and limited. Authentic activities were a major feature of Cases 2 and 3. In Case 2, students developed testable questions, formed reasoned hypotheses, planned and carried out fair tests that involved controlling variables, and reported and evaluated their findings. In Case 3, students made and recorded detailed observations, critiqued each other's observational drawings, planned and carried out investigations, interpreted data and reported findings. Some students incidentally engaged in conjecture and debate over theories, which are forms of scientific discourse, although this was not recognised or structured by T3. The

nature of science learning opportunities provided through students' participation in authentic activities was largely syntactic in Case 2 where the focus was on learning to use fair testing processes, although students reported learning about the topics they investigated as well. In Case 3, students had opportunities to learn both substantive and syntactic ideas while engaging in science practices; there were opportunities to learn about heart structure and function while examining real hearts, for example.

Participation in authentic activities in Cases 2 and 3 enabled acts of enculturation including use of scientific vocabulary and textual forms such as diagrams (Case 3) and orderly recording formats such as tables (Cases 2 and 3). However, enculturation into use of scientific vocabulary and interpretation of diagrams also occurred in Case 1 where authentic practices were not prevalent. Participation in authentic practice provided opportunity to learn syntactic aspects of science, the processes and values associated with the practice of science such as controlling variables, rigour, attention to detail, collegiality, accuracy and orderliness in recording observations. Such opportunities were not apparent in Case 1 where authentic activities were uncommon and unstructured. T1's orientation to teaching science limited opportunities for use of authentic activities, as did the school's location, distant from the rocky shore. Participation in authentic activities was enhanced by T2's process and T3's guided inquiry orientation toward the teaching of science.

Other participatory sociocultural strategies that provided opportunities for science learning included participation in joint enterprise as observed in Classes 1 and 3. The creation of this joint sense of ownership encouraged student participation in science learning opportunities. The nature of the enterprise they engaged in again depended on each teacher's orientation to teaching science.

The staged tasks used by T2 allowed explicit definition and clarification of the steps involved in fair testing, providing opportunities to appreciate the rigour and focus required when investigating in science. T3 also used a staged task to emphasise the accuracy and rigour required in collecting data scientifically.

Use of examples of expert practice occurred in all cases: T1's informal example of classification; T2's provision of a completed planning format and written criteria; T3's personal examples of scientific thinking when planning an investigation, and use of examples of scientific texts and diagrams. Examining the sources of examples,

those used for practical situations were all provided by the teacher or, occasionally, a student's behaviour was noted and highlighted by the teacher. Expert examples of scientific textual forms were readily available for teacher use from books and the internet, but examples of science processes and values were dependent on teachers' syntactic knowledge. This will be discussed further in connection with distributed cognition.

In each case the situated nature of the participatory activity offered students opportunities for learning about the nature of science. In Case 1 visiting the rocky shore allowed an opportunity for students to encounter rocky shore creatures in their natural surroundings, that is, an opportunity to see science as exploration of the natural world. In Case 3, students were investigating their own fitness and that of their peers, so there was opportunity to see the application and relevance of science to their lives. Students in Case 2 had similar opportunities through their use of science to investigate topics and issues of relevance to them.

All three teachers structured students' interaction with aspects of science. T1 used structured interaction in interpreting food chains. T2 frequently used this strategy to introduce a new stage of the fair testing process, for example, hypothesising. T3 structured students' interactions with both the cultural tools and processes of science, such as use of diagrams and planning an investigation. Structuring students' interaction provided a mechanism by which scientific tools and practices could be clarified. This and other forms of guided participation served as a means of enculturation into science. Teachers' use of mutual bridging of meanings was not common, but most often used in conjunction with developing scientific vocabulary. All three teachers established instructional congruence for science with students' experiences, commonly through use of familiar contexts. For example, T1 used an agricultural example to help students understand photosynthesis; T2 used contexts such as milk absorption by cereals to teach about variables; T3 used the schools' students as a context for fitness investigations. Use of familiar contexts relied on the teachers' contextual knowledge of students and the school community as well as their ability to recognise the science in these contexts, linking with their content knowledge. T1 used narrative in the form of stories from his childhood to develop understanding of tides. Narratives about science and scientists were not used by any of the teachers to develop understanding about the nature of science. Use of routines or role plays was not observed, neither was deliberate enculturation into scientific discourse such as debate and argument.

The final aspect of sociocultural practice examined was distributed cognition. In Classes 1 and 3 technological tools in the form of computers and the internet were readily accessible and used by students during science lessons as a tool for locating substantive information. Students in Class 2 were expected to locate information about their investigation topic in their own time. Students in Classes 1 and 3 had access to a wide range of books relating to the science topic they were studying. Other forms of scientific symbolic tools were made available: T1 and T3 provided scientific texts such as food webs (Case 1), annotated cross sectional diagrams and scientific explanatory reports (Case 3). In Class 2, the symbolic tools available were developed by T2: the written criteria that documented the expected features of the stages of the fair testing investigation and completed planning formats that provided expert models of practice. These tools corresponded to use of cultural tools discussed earlier in conjunction with socially mediated learning as cultural scaffolding.

The use of other students in the class as a resource and thinking tool was prevalent in all three classes and equates with use of socially mediated learning as participatory knowledge construction, discussed earlier in this section. The nature of the communicative approach used by T1 and T3 broadened the distribution of cognition by allowing student ideas that had been identified through use of symbolic and technological tools to be made available for other students, whereas the evaluative discourse that dominated Class 2, while allowing students' ideas to be clarified, meant ideas were largely constrained to T2's syntactic understanding concerning science investigation.

A further category of distributed cognition was identified during the study: natural objects. It was observed that natural objects such as fresh animal hearts and lungs were made available as thinking tools for students in Class 3 and that natural objects had been made available in the other cases also. In Case 1, students examined the inhabitants of the rocky shore in their normal habitat. In Case 2 students investigated natural objects such as sugar content of biscuits with the purpose of learning how to investigate, but also studied natural objects in their own investigations. In Case 3, not only were fresh animal organs provided for study, but the fitness of students from other classes was investigated and students examined aspects of their own bodies such as lung capacity. The extension of the distribution of cognition to include such objects seems logical for science, as its focus for study is the natural world.

When considering these descriptions of distributed cognition, it can be seen that each teacher was using the tools of cognition available to implement their particular orientation to teaching science, which again heavily influenced the nature of science opportunities afforded. T1's widely distributed cognition was used in development of substantive science knowledge. In Case 2, the limited range of cognition provided opportunities for students to develop their use of science processes. In Case 3, T3's guided inquiry orientation and widely distributed cognition afforded both syntactic and substantive opportunities.

Tools to support substantive science development were more readily accessible to these teachers than tools that supported syntactic development. Symbolic and technical tools providing opportunities to learn substantive ideas were plentiful in the form of books and internet articles about life at the rocky shore, or about the structure and function of the heart and lungs. Examples of symbolic or cultural tools such as annotated diagrams and models were also readily accessible, thus allowing T3 to use these as examples of expert practice and facilitating students' use of them as tools. Tools in the form of expert examples of use of scientific processes, as required by T2, were not common; she had to develop her own models. Similarly in Case 3 the examples of scientific values and thinking that were exhibited were T3's own. The range of cognitive tools that the teachers in this study drew on to support syntactic learning opportunities regarding scientific processes and values was restricted. All three teachers provided access to natural objects for students, but in order to assist students to investigate these objects scientifically, T2 and T3 drew on their own syntactic knowledge. Examples demonstrating expert scientific practice and values may have supported these teachers in providing syntactic science learning opportunities.

All three teachers' use of sociocultural approaches afforded many opportunities for science learning. The nature of these opportunities generally reflected each teacher's orientation to teaching science. This was particularly so for socially mediated actions. Participation in authentic activities created most opportunity for syntactic science learning with regard to scientific processes and values. T2 and T3's orientation to teaching science was characterised by use of authentic activities. Staged tasks provided opportunities for making scientific processes clear. The situated nature of participatory learning afforded opportunities to learn about science but may have limited opportunities to engage in authentic activities in Case 1. Structuring of interactions, a form of guided participation, and establishment of instructional congruence with students' existing language and experience provided

mechanisms for enculturation into use of scientific practices, texts and vocabulary. The potential of routines and role plays in providing science learning opportunities was not explored, perhaps because teachers were unaware of their possibilities, or perhaps because these were not a normal part of their teaching repertoire. While narrative was used to provide opportunity for development of substantive ideas, none of the teachers in this study used stories about science. They may not have known of such stories or did not realise their potential as syntactic learning opportunities. Deliberate enculturation into the use of scientific forms of dialogue such as debate and argument was not observed, perhaps because teachers did not see these discourse types as part of the practice of science, a possible limitation of their syntactic science content knowledge. Widely distributed cognition through the availability of symbolic and technological tools and natural objects, enhanced by the availability of other students and their ideas, provided many substantive learning opportunities and opportunities to learn to use some of the symbolic tools of science. However, tools, other than those developed by teachers themselves, that provided learning opportunities focussing on scientific processes and values were either not available or not recognised.

7.2.4.3 Classroom management and organisation

Reviewing the evidence presented in Sections 4.2.1.3, 5.2.1.3 and 6.2.1.3 shows that all three teachers used their knowledge of classroom management and organisation to maximise the time spent on science tasks. In particular, the setting of clear expectations, frequent provision of feedback and almost constant monitoring of student performance, factors which related to the teachers' beliefs about the purpose of assessment, provided opportunities for clarification of intended learning in science and identified when to implement additional learning opportunities to address needs in science. As with other knowledge domains, the focus for feedback, monitoring and the expectations set depended on each teacher's orientation to teaching science, what they believed was the focus for science learning.

7.2.4.4 Classroom communication and discourse

Evidence presented in Chapters 4, 5, and 6 pertaining to the communicative approaches used in each case show that an interactive dialogic approach was the predominant form of discourse in Cases 1 and 3. Use of this approach contributed to the observed sense of joint enterprise present in these classes. It facilitated T3's co-construction with students of key features of scientific texts, processes and values. The focus of the dialogue in Class 1 was substantive knowledge and T1 occasionally used authoritative non-interactive discourse to summarise and restate

substantive science ideas that had been discussed. T3 used a more authoritative approach to clarify and emphasise important points, both syntactic and substantive, and to set expectations. Both teachers used their approaches to ensure students articulated important ideas, although they also both paraphrased and restated these ideas to clarify them and make them available for all students.

In Case 2 the communicative approach, though often interactive, tended to be more authoritative; however, these interactions still presented learning opportunities for science, just not as participatory as in Cases 1 and 3. T2 used authoritative non-interactive discourse for review, general feedback, to explain tasks and set expectations. Interactive communicative approaches, both dialogic and authoritative, were used to monitor student performance and provided opportunities for students to identify and improve their competence with stages of the fair testing process. Each teacher's orientation to the teaching of science again governed the nature of the learning opportunities afforded through their knowledge of classroom communication and discourse.

This section discussed the opportunities for science learning provided by the teachers' use of general pedagogical knowledge. The evidence suggests that the teachers in this study used the knowledge in this domain to provide and support many opportunities to learn the type of science afforded by their orientation to teaching science. Their general pedagogical knowledge provided the means by which they could teach the science they saw as the focus for learning. Sociocultural approaches to teaching used by T2 and T3 afforded more syntactic learning opportunities than did the social constructivist approach of T1, although sociocultural strategies used by all three teachers provided science learning opportunities.

7.2.5 Curriculum knowledge and beliefs

This section uses evidence from Sections 4.2.6, 5.2.6 and 6.2.6 to examine the opportunities for science learning afforded by the teachers' knowledge and beliefs about curriculum.

T3's expressed general educational aims and observed practice concerning group work aligned with the vision of the New Zealand Curriculum and the key competencies it describes as desired outcomes (MOE, 2007). T1's aim that his students become independent learners, similarly aligned with one of the principles of the National Curriculum Framework, the overarching curriculum document that was current at the time of observation (MOE, 1993a). It was unclear whether the

documents had influenced these teachers' aims or simply aligned with them. The influence of knowledge of these broader documents on the opportunities afforded for science learning is unclear.

Data for Cases 1 and 2 were collected when the curriculum document *Science in the New Zealand Curriculum* (MOE, 1993a), had been in place for thirteen years. T1 suggested its two integrating strands, the Nature of Science and its Relationship to Technology strand and the Developing Skills and Attitudes strand, were an important guide for science teaching and learning. However, in practice his focus was almost entirely on the development of substantive understanding relating to achievement objectives from the Living World contextual strand concerning classification, habitat and food chains. The nature of learning opportunities presented in Case 2 linked closely to objectives from both the integrating strands which, at the levels appropriate to T2's students, focused largely on fair testing.

T3 stated that the major focus for her teaching was the nature of science which she taught in the context of the Living World strand. This contextualised focus on the nature of science, together with the inclusion of a range of investigation types, reflected the direction prescribed for science in the 2007 curriculum that had been in place for eighteen months at the time of the observed unit. It was unclear whether T3's focus was in response to the curriculum or simply aligned with it. Information from a school science review led by T3 in 2005-6 suggested her focus on the use and range of investigation in science preceded the introduction of the new curriculum.

As will be discussed in Section 7.2.7, all three teachers had a different orientation to the teaching of science. The curriculum appeared to have less influence on the kind of science learning opportunities provided than each teacher's orientation to teaching science. However, the similarity between the nature of teacher content knowledge and achievement objectives contained in the curriculum suggests a possible influence of the science curriculum on the development of teacher content knowledge and will be discussed in Section 7.3.

The teachers' beliefs about vertical curriculum for science impacted on science delivery in conjunction with their general aims for their students pertaining to transition to secondary school. T1 used secondary school as a justification for students recording tidy notes in science and for students being able to locate scientific information. T2 believed fair testing underpinned secondary school

science, a belief that could be vindicated in the light of the then curriculum. T3 believed she was giving her students a foretaste of the kind of science they would experience at secondary school. It seems that in all three cases the teachers' beliefs about the nature of secondary school science supported the nature of the opportunities for science learning they provided. They all believed they were helping to prepare their students for their next educational experience in science.

Knowledge of horizontal curriculum supported science learning in Cases 2 and 3. Little connection to other learning areas was made in Case 1, perhaps because T1's situation as a teaching principal meant he did not take his class for all subjects. In Cases 2 and 3, other learning areas, health in particular, provided authentic contexts for science learning. Exploring health issues provided opportunity to see the utility of science in informing personal decision making. Learning in English both supported, and was supported by, science in Cases 2 and 3. T2 deliberately planned teaching of procedural writing and explanations to support students with the writing required in their science fair projects. Whilst students were writing in science, opportunities arose to work on individual literacy needs. In Case 3, information gathering during science concurrently provided opportunities for English in learning to use parts of speech as key words and for substantive science learning. T2 timed the teaching of statistics to support science investigations. T3 used data collected during science as a context for interpreting statistical information. The aspects covered were then used to assist interpretation in later science investigations. T2 and T3's knowledge of other learning areas, especially English and mathematics, therefore supported learning in science but also facilitated learning in other areas through science.

The final category of curriculum knowledge concerns resources. All three teachers demonstrated knowledge of a wide range of resources useful for science, locating and using scientific equipment that provided opportunities for science learning. T3 used a variety of everyday equipment for science.

T1 and T3 obtained and used topic related books containing relevant substantive science ideas to support student science learning from the school service of the National Library, thereby distributing cognition more widely. T3 also used activities and examples of scientific communication tools from these books, thus increasing science learning opportunities. T1 used an activity from the internet about food chains. The nature of books that could have been used with students to support T2's teaching of process is less obvious.

All three teachers were aware of the *Building Science Concepts* and *Making Better Sense* series of science teaching resources provided to schools by the MOE. T1 said he used the *Building Science Concepts* books in preparing to teach the observed science unit. Their use by any of the teachers was not observed. T1 and T3 both found and used ARB assessment tasks on their topics. All three teachers knew about the *Connected* series of school journals but their use was not observed in any of the cases. The *Science IS* section of MOE teacher support website (www.tki.org.nz) available at that time would have provided some support for syntactic aspects of science but was not referred to or used by any of the three teachers. The *Science Exemplars* (MOE, 2004) which support assessment of syntactic aspects of science were only introduced to T3 by a colleague toward the end of the unit, although they had been available in schools for five years. Although resources affording development of substantive ideas were plentiful and easily located, fewer resources were available to support syntactic aspects of science and the teachers were unaware of them.

The teachers' knowledge and beliefs concerning the science curriculum were less of an influence on the opportunities provided for science learning than was their orientation to teaching science. The teachers' beliefs about vertical science curriculum supported the nature of activities they included and could be seen as a possible constraint to science learning, particularly in Case 2. In Cases 2 and 3, the teachers' knowledge of horizontal curriculum afforded support for learning in science whilst science also afforded opportunities for learning in other areas. Finally teachers' knowledge of resources in the form of equipment afforded science learning opportunities. Whilst teachers' knowledge of substantive science teaching materials provided science learning opportunities in Cases 1 and 3, knowledge and use of teaching materials that would support syntactic science learning was not observed in Cases 1 and 2 and limited in Case 3.

7.2.6 Science content knowledge and beliefs

In this section the evidence presented in Sections 4.2.5, 5.2.5 and 6.2.6 is used to consider how the two categories of the science content knowledge domain influenced science learning opportunities. The science content knowledge and beliefs exhibited by each teacher is summarised in Table 7.1.

7.2.6.1 Syntactic knowledge and beliefs

All three teachers displayed knowledge and beliefs about the nature of scientific knowledge and its generation. Comments suggest they all saw science as empirical, involving observation and investigation of the natural world, and as contestable, involving critical consideration of claims. T1 saw science knowledge as changing

over time in response to improving technology. From observations it was clear that T2 understood the process of fair testing, but also that her perception of scientific investigation was limited to this form. T2 and T3 both emphasised rigour in accuracy of observation, orderly recording of observations and control of variables and displayed other syntactic knowledge and beliefs as they engaged students in authentic activities. T3 engaged her students in a range of investigation types. It appeared that opportunities to observe her students as they engaged in such practices triggered aspects of her syntactic knowledge which she then made explicit.

T2 provided expert examples of syntactic aspects of science by modelling scientific practice such as accurate measuring. She also formalised her knowledge concerning the nature of an investigable question, reasoned hypotheses, accurate measuring and orderly recording of data, and the nature of scientific reports of investigations in written success criteria to be used by students as they developed and critiqued their own investigations. T3 used class discussion and co-construction and her own and student examples of expert practice to make her syntactic knowledge explicit for students. T1 made little formal use of authentic activities and little opportunity for students to develop syntactic knowledge was observed, although this may have occurred informally during the field trip as T1 interacted with students as they explored the rocky shore.

In Cases 2 and 3, the teachers' orientation to teaching science facilitated their use of authentic activities. In Case 2 the nature of the topic meant T2's syntactic knowledge was critical, particularly given the narrowness of distributed cognition observed in this case. Student participation in authentic activities provided opportunities for T2 and T3 to make their syntactic knowledge and beliefs explicit. T2 and T3's range of syntactic knowledge afforded many opportunities for students to learn about syntactic aspects of science, although T2's beliefs concerning fair testing limited her students' learning opportunities regarding scientific investigation to this form; other forms of investigation were seen as unacceptable for students to use in the science fair. That students completed their own investigations at home also limited syntactic learning opportunities. Use of authentic activities would not have been precluded by T1's academic rigour orientation to teaching science; however, little use of his syntactic knowledge was observed.

7.2.6.2 Substantive knowledge

As required by his academic rigour approach, of the three teachers, T1 exhibited the widest range and depth of substantive knowledge. The nature of the topic studied in Case 2 meant there was limited opportunity to observe T2's substantive knowledge.

T3 was teaching a topic new for her, so her case presented an opportunity to observe substantive knowledge as it was developed. Despite these limitations and differences, all three teachers demonstrated knowledge of higher order concepts and principles. T1 exhibited knowledge of concepts regarding classification, energy transfer through ecosystems, adaptation and habitat. T2 demonstrated understanding of key aspects of particle theory relating to chemical change. T3 recognised that the fitness topic was an opportunity to develop understanding relating the structures of the heart and lungs to their function. In all three cases concepts reflected the focus of achievement objectives from the 1993 science curriculum document (MOE, 1993a). This may be coincidental as the possibility of a link was not explored during data collection, but may also suggest that familiarity with the requirements of curriculum documents may have provided a guide for knowledge development.

T1 demonstrated a depth of detailed topic specific and non-target content knowledge that allowed him to use different contexts to make target concepts clear. In comparison, T3's topic specific knowledge was limited and developed as required and as the unit progressed. However, detailed content knowledge regarding the structure and function of the key features of the heart and lungs was observed. In both these cases the teachers' knowledge of key concepts guided the intended substantive learning outcomes and governed the choice of activities. This effect could be perceived as restricting learning opportunities within a context, but in the observed cases it contributed to a clear focus and direction for science learning.

Differences in depth of knowledge exhibited in these two cases relate to their different orientations to teaching science. T1's academic rigour approach demanded strong substantive knowledge. While the depth of his knowledge provided rich and multiple opportunities for students to build understanding of both key concepts and detailed topic specific ideas, in the longer term his approach would be constraining and self limiting in that, as he stated, he only chose to teach topics that he was confident about. Both T3's general inquiry approach and her orientation to teaching science meant that she was accustomed to exploring topics she felt were of interest to her students. Her personal knowledge was not a consideration in choosing the topic. She decided to teach the fitness unit even though she lacked confidence in her topic specific content knowledge. In the observed case, because of the widely distributed cognition, both T3 and her students accessed a range of topic specific content knowledge. In the longer term, T3's approach would afford her a greater range of content knowledge. The development of the teachers' knowledge for science teaching is discussed further in Section 7.3.

In all three cases the teacher's content knowledge provided opportunities for learning in science; the nature of those opportunities and the nature of the knowledge required and used by the teacher depended on their orientation to teaching science.

7.2.7 Science pedagogical content knowledge

The greatest influence on the nature of opportunities for science learning in each case was the teacher's orientation to teaching science, a component of teachers' PCK that Magnusson et al. (1999) describe as referring to "teachers' knowledge and beliefs about the purposes and goals for teaching science at a particular level" (p. 97). Arguments supporting identification of each teacher's orientation were presented in Sections 4.2.7, 5.2.7 and 6.2.7.

Although T1 said that he wanted students to develop scientific skills and attitudes and to understand that science involved experimenting, his practice was dominated by a focus on gathering information from books and the internet. He encouraged students towards understanding difficult concepts such as photosynthesis and energy flow through ecosystems and the interconnectedness of the natural world. This focus aligns his orientation with the academic rigour approach described by Magnusson et al. (1999) where the goal is to "represent a particular body of knowledge" (p. 100). This orientation provided many opportunities for complex and deep substantive learning. However, there was very little opportunity to participate in authentic activities and therefore to learn syntactic aspects of science such as processes and values. Information from books and the internet was accepted as fact, limiting opportunities to see science knowledge as contestable.

T2's focus was on learning to investigate. The progression of the unit steadily moved through the development of each step in a fair test. Magnusson et al. (1999) describe the goal of a process approach as "helping to develop science process skills" (p. 100). The nature of opportunities afforded by this orientation included developing an investigable question, writing a reasoned hypothesis, controlling for variables, and reporting results in an orderly way. Students had multiple opportunities to participate in, practise and clarify these science processes. They then used them in their own investigations. Applying their science learning to topics of personal interest afforded opportunities to appreciate both the way science knowledge is generated and its application in real world contexts. As this case was not linked to a specific context, opportunities for substantive learning were limited. Any such opportunities lacked a common conceptual focus.

In Case 3, students and teacher acted as “a community of learners whose members share responsibility for understanding the physical world, particularly with respect to using the tools of science” (Magnusson et al., 1999, p. 100). This guided inquiry orientation afforded students both syntactic and substantive learning opportunities through participation in authentic activities, observing and exploring organs and investigating their own and others’ fitness. They had opportunities to develop substantive ideas about the structures and functions of the heart and lungs, while at the same time learning to use scientific communication tools such as models, diagrams and reports. The joint focus in this orientation on understanding the natural world, while using the tools of science, afforded opportunity to learn knowledge created by science as well as the ways in which scientific knowledge is generated.

The teachers did not use a wide range of the science specific instructional strategies that form part of PCK. Science learning opportunities came largely from use of the teachers’ general teaching approach and strategies, as described in Section 7.2.4. T2 and T3 used demonstrations to show how to carry out scientific procedures. T3 also used demonstrations as an opportunity to learn about heart and lung structure and function. Representations, such as diagrams and models were used to convey substantive ideas in Case 1, while in Case 3 students had opportunities to use these tools to convey their developing ideas. Activities from books, the internet, or other teachers, i.e., activities that work (Appleton, 2002), were used by all three teachers. T3 used a range of activities from books: these provided useful opportunities to participate in scientific observation, as in the sweaty hand investigation, and for substantive learning in the case of model making.

Use of scientific discourse was not used deliberately as a strategy by any of the teachers, despite all recognising that contestability of claims was a feature of science knowledge generation. Facilitating debates and developing formal arguments around possible explanations using evidence would have been ways for students to experience this aspect of science.

T2 and T3 used aspects of their general pedagogy to teach syntactic science ideas. Use of authentic activities usually facilitated these learning opportunities. T2 most often used success criteria and T3, co-construction. T2 used activities that had been successful in teaching elements of fair testing with previous classes. These could be considered syntactic PCK as they had become part of her ‘repertoire’ for teaching fair testing, the use of the cereal investigation to teach about variables for example.

T3 was observed developing PCK for managing practical activities and use of animal organs to develop substantive knowledge.

Knowing what to assess in science is part of PCK. In each case, the teacher's focus for assessment aligned with their orientation to teaching science. T1 looked for development of key concepts such as being able to explain energy flow through complex food chains. T2 assessed students' ability to use the processes of science. T3 assessed both students' understanding of heart and lung structure and function, and their ability to plan and carry out an investigation. All three teachers used general assessment methods such as discussion, observation and marking work for formative assessment. T3 made use of group and self-assessment. They all used formal science assessment resources for summative assessment. T1 and T3 used ARB science assessment tasks and T2's formal summative assessment was developed from the judging criteria used at the regional science fair. T3 used the *Science Exemplars* (MOE, 2004) as a guide to assessing students' syntactic learning about planning and carrying out investigation. She felt such assessment would be useful for school review and to inform later science teaching. No such understanding of assessment to inform ongoing teaching and learning in science was observed in the other teachers.

Limited knowledge of common student difficulties was exhibited, and what was observed had mostly developed through repeated teaching of the same topic, such as T2's acknowledgement that students generally found it difficult to develop an investigable question. All three teachers used diagnostic assessment initially, and formative assessment throughout their science teaching to identify particular needs of students in the group.

It seems that general pedagogical knowledge replaced the need for specific PCK in much of the teaching observed. Activities that work were used by all three teachers and in T2's case had become part of her PCK for the science fair topic. Science PCK was used with regard to ways to formally assess students' science learning, but the focus for assessment depended on the teacher's orientation to teaching science.

7.2.8 Summary of findings for Research Question 1

Findings show that the three teachers in this study utilised knowledge from each domain in implementing the observed science unit. Knowledge domains impacted singly and in combination to facilitate provision of opportunities for science learning and influence the nature of those opportunities. The nature of influence of each domain on learning opportunities for science is summarised in Table 7.2.

Table 7.2: Summary of influence of each knowledge domain on opportunities for science learning

Knowledge domains and categories	Influence on science learning opportunities
Knowledge of and beliefs about general aims, purposes and values	
Education	Provision of opportunities and nature of content and activities
Assessment	Provision of additional opportunities and learning goals
Knowledge of and beliefs about learning and learners	
Learning and human development as it informs practice	Nature of opportunities
Student characteristics (Generalised for a particular age or year group)	Little identified
Knowledge of and beliefs about the educational context	
New Zealand school system and structures including governance and financing of schools	Provision of opportunities: staffing
Character of the New Zealand community including its social, political, cultural (including bicultural emphasis) and physical environments	Little identified: some influence on nature of activities through use of common NZ experiences Little acknowledgement of bi-cultural context
Workings and character of the school including its social, political, cultural (including bicultural emphasis) and physical environments	Provision of opportunities: budgeting, accessing parent support, joint science planning, timing of other learning areas to support science
Knowledge of particular students including their social, political, cultural (including bicultural) backgrounds and attitudes together with knowledge of their abilities, learning strategies, developmental levels, attitudes, motivations and experiences	Informed by assessment Provision and nature of opportunities: informed structure of groups, selection of topic, support for individual needs
General pedagogical knowledge and beliefs	
General instructional strategies and teaching approaches	Provision and nature of opportunities: practical activities and discussion provided opportunities, nature and purpose of which varied with teaching approach and orientation
Classroom management & organisation	Provision of opportunities: time spent on science opportunities, feedback, clear expectations
Classroom communication and discourse	Provision of opportunities: nature of discourse influenced the range of ideas available
Curriculum knowledge and beliefs	
New Zealand wider curriculum documents (MOE, 1993b, 2006, 2007)	Some alignment of beliefs, aims and practice but influence difficult to determine
Specific curriculum documentation pertaining to science found in <i>Science in the New Zealand Curriculum</i> (MOE, 1993a), <i>NZ Draft Curriculum</i> (MOE, 2006) and <i>The New Zealand Curriculum</i> (MOE, 2007)	Some alignment with teachers' aims but influence on practice difficult to determine Alignment of content knowledge with contextual achievement objectives suggests possible influence on nature of content
Vertical (higher and lower levels within science)	Provision and nature of opportunities
Horizontal (curricula of different subjects at same level including PCK from other subjects)	Provision and support of opportunities (Cases 2 and 3)
Resources	Provision of opportunities
Science content knowledge and beliefs	
Syntactic knowledge of science	Afforded and constrained provision and nature of opportunities (Cases 2 and 3)
Substantive knowledge of science	Afforded and constrained provision of opportunities

Knowledge domains and categories	Influence on science learning opportunities
Science PCK and beliefs	
Orientation toward science teaching	Major influence on nature of opportunities
Knowledge of science instructional strategies	Provision of opportunities. Little use of scientific discourse
Knowledge of science assessment	Focus for assessment determined by orientation toward science teaching
Student preconceptions and difficulties	Provision and nature of opportunities

The teachers' orientations to science teaching, in each case mediated by knowledge from all domains, strongly influenced the nature of learning opportunities in science. The nature of opportunities provided by each orientation is shown in Table 7.3.

Table 7.3: Nature of opportunities provided by each teacher's orientation to teaching science

	Orientation to teaching science	Nature of opportunity for science learning afforded	Examples of focus for learning opportunities
T1	Academic rigour	Substantive	<ul style="list-style-type: none"> • Nature and cause of tides • Characteristics of classes of rocky shore animals • Photosynthesis and importance of producers • Energy transfer through food chains
T2	Process	Syntactic	<ul style="list-style-type: none"> • Identifying and controlling variables • Developing a relevant testable question • Developing a reasoned hypothesis • Features of a fair test • Orderly recording of observations • Writing a scientific conclusion
T3	Guided inquiry	Syntactic	<ul style="list-style-type: none"> • Features of a cross sectional diagram • Scientific data need to be interpreted and presented in forms that make sense to others • Finding patterns in data is a form of scientific investigation • Scientific investigation requires methodical planning, detailed observation and orderly recording • Repeating and averaging measurements improve validity
		Substantive	<ul style="list-style-type: none"> • Making and using models of heart and lungs • Heart and lung structure and function

Of the three orientations observed, the guided inquiry orientation exhibited by T3 provided the widest range of opportunities for science learning, as both syntactic and substantive opportunities were afforded and supported; however, all three teachers provided many valuable opportunities for learning science.

7.3 Development of the knowledge needed for teaching science

The second research question guiding this study sought to explore how the teachers in the three cases developed the knowledge they needed for their science teaching. The knowledge domains particular to science teaching are science content knowledge comprising syntactic and substantive knowledge, and science pedagogical content knowledge (PCK). As described in section 7.2, the teachers' orientation to teaching science had significant influence on the nature of science learning opportunities and, although part of PCK in the framework used for analysis, will be discussed separately. This section analyses and discusses evidence presented in Sections 4.3, 5.3 and 6.3.

Professional development is a potential source of knowledge development. T1 and T2 had experienced no recent professional development in science. T1's only reported opportunity was in 1993 in conjunction with the introduction of the science curriculum (MOE, 1993a). T2 reported having had no professional development in science. T3's school had undertaken professional development in science in 2005-6. This was initiated and organised by the school. T3 did not refer to this professional development as supporting her science teaching but it may have been an influence.

Four processes were identified in Case 3 as contributing to knowledge development: intentional knowledge development, reflection, repetition, and engaging and observing students in investigating the natural world. The other two cases were examined in the light of these findings to see if these processes applied or not.

The results of this analysis are shown in Figure 7.1.

Figure 7.1: Diagram showing the ways teachers in this study developed their science content knowledge and PCK

Existing and new science content was commonly taught by all three teachers using their normal general pedagogical approach.

Intentional development of knowledge for science teaching was exhibited by all three teachers. T1 and T3 both developed substantive science knowledge through reading and searching the internet. T2 had intentionally developed her syntactic science knowledge over time through working with a teacher experienced in science, discussion with school science fair judges, and examining guidelines, criteria and winning exhibits from the regional science fair. T3 drew on background syntactic knowledge during the observed unit, claiming she was “just aware” of how to control variables, for instance (T3/1/29/7).

Intentional development using books and the internet provided PCK in the form of activities that work in Cases 1 and 3. T1 located an activity regarding food chains through searching the internet and T3 found several practical investigations in books. Intentional development of PCK was also exhibited in Case 3 where teachers in T3’s syndicate practised activities together, for example inflating the lungs, before introducing them in the classroom. T3 also sought advice from colleagues regarding assessment of science processes, eventually identifying the *Science Exemplars* as a support (MOE, 2004).

The preceding discussion shows that both syntactic and substantive content knowledge and aspects of PCK were developed intentionally. However, syntactic and substantive content knowledge were not equally accessible to the teachers, as described in Section 7.2.4.2. There were multiple sources readily available to T1 and T3 for development of substantive knowledge. T3 was able to build detailed content knowledge about the heart and lungs from books and the internet. Syntactic knowledge was not so readily available. T3 relied on her background syntactic knowledge. T2 actively sought sources of syntactic knowledge. The few reifications of practice that she found in the form of science fair guidelines and exhibits supported her belief in the importance of fair testing, limiting the development of her knowledge. As outlined in Section 5.2.6, the science curriculum document and related science teacher resources would also have reinforced these beliefs. Resources that were available that would have supported syntactic knowledge development such as the *Science Is* website (www.tki.org.nz) and the *Science Exemplars* (MOE, 2004) were either not familiar to these teachers or not recognised for their potential.

Reflection on practice was exhibited by T2 and T3 in developing science PCK. T3's reflection on the benefits for learning of involving students in scientific investigations and her use of natural objects reinforced their use. Opportunity for scientific investigation had become one of her criteria for topic selection in science, which could be considered PCK for science. Her reflection on ways to develop questions had also resulted in more effective strategies that were useful for science. T3's reflection on her practice resulted in development of her science PCK with regard to ways to optimise her time with students engaged in key practical experiences.

Reflection by T2 on the application of a newly acquired general pedagogical strategy to teach syntactic science knowledge was observed as she implemented a question generating activity. Such reflection in the past had resulted in the inclusion in the observed unit of activities from previous iterations of the same unit: activities that had worked had become part of her syntactic PCK for teaching about science fair.

Repetition played a key part in the development of T2's syntactic PCK and is the third process through which development of knowledge for science teaching was demonstrated in this study. Repetition had facilitated T2's knowledge of common student difficulties, a part of PCK, in developing questions for science fair. T3 was observed to develop PCK for teaching about structure and function using a sheep's heart and lungs through repetition of the same activity with different groups.

The final process contributing to development of knowledge needed for science, observed in Case 3, was engaging students in investigating the natural world. Investigating with her students facilitated development of T3's PCK using the processes described in the above examples. It also activated her syntactic knowledge, which she then taught using her general pedagogical strategies.

The nature of PCK that T1 and T3 developed intentionally through accessing resources included instructional and assessment strategies for topic specific substantive knowledge. Engaging students in practical science, together with reflection and repetition, in T3's case, produced further topic specific instructional strategies together with syntactic PCK more generically useful for teaching science, such as strategies for managing practical activities and evaluating a topic for its potential for student investigation. T2's development of syntactic PCK could be similarly applicable to other contexts and topics.

Having the confidence to begin to investigate a new topic with her students was important in T3's case. Confidence and persistence in investigating appeared to have been important long-term components of her science teaching practice. T2 exhibited confidence in that she had been prepared to take on leadership in the science area with little experience and took steps to develop the knowledge she needed for teaching science fair. She was also confident in leading practical investigations with her class. T1 was confident in leading the rocky shore trip, but did not display confidence to try new topics, largely because his orientation to teaching science required depth of knowledge. Lack of confidence would ultimately restrict his knowledge development whereas T3's confidence to try new topics allowed her content knowledge to expand.

With regard to substantive knowledge development, both T1 and T3 exhibited knowledge of general principles and concepts relating to the topic being studied. T3's detailed content knowledge developed around the general concept of the interrelationship of structure and function pertaining to the heart and lungs. T1's knowledge of general concepts included principles of classification and concepts of energy transfer through food chains. T2's substantive knowledge related to chemical change. These general concepts all relate closely to the focus of the Level 3 and 4 achievement objectives of the 1993 curriculum (MOE, 1993a), suggesting it may have been an impetus for development of their knowledge. However, there is no other evidence to support this claim.

Each teacher's knowledge for science teaching developed according to their orientation to teaching science. T1 added to his substantive knowledge and T2 attempted to build her syntactic knowledge. T3 intentionally developed her substantive content knowledge but her orientation to teaching science meant she engaged her students in doing science which enabled PCK development such as evaluation of contexts for investigation potential.

The development of the teachers' orientation to teaching science, although categorised as part of PCK for analytical purposes in this study, does not appear to have its origins in the processes outlined above. This category appeared based more in each teacher's individual beliefs about the purpose and nature of science teaching. There is a little evidence that suggests possible origins of beliefs leading to the observed orientations. T1 suggested that the integrating strands of the 1993 curriculum, then current, should underpin science teaching, a view depicted in this document by illustrations of the interwoven nature of the integrating strands with the contextual strands (MOE, 1993a). Such beliefs would have been expected to support

an orientation focused on the nature of science and the skills of scientific investigation. This was not what was observed in lessons. T1 held strongly a view, resulting from professional development in science early in his career, that science knowledge best explains the natural world as a series of interrelated systems. These beliefs influenced his purpose for science teaching in the observed unit. His stated purpose was to develop “an understanding of how all life is interrelated” (T1/I/5/3). His focus on understanding the major concepts connecting the influence of tides, adaptation, and energy interrelationships in food chains aligns with this purpose, suggesting a possible explanation for the academic rigour orientation to teaching science manifested in his teaching. This orientation was also supported by his general aims and beliefs about the importance of developing independent learners and the use of information technology in this regard.

Observing the science fair unit may have been limiting in terms of describing T2's orientation to teaching science, as such a unit would naturally focus on the process of investigation. Comments by T2 suggest that fair testing was a specific focus for all her science teaching: “Science fair is the big project but we also try incorporate fair testing with our other units in the school...we've done two strand units a year and we've focussed on fair testing as part of that...” (T2/I/18/5). She held a strong belief in the value for her students' future science education, which aligned with her general aims, of knowing how to carry out a fair test. The emphasis on fair testing in the then current curriculum and supporting resources was described in Section 5.2.6. This emphasis may explain her beliefs about the significance of fair testing and the observed process orientation to teaching science. Her orientation to teaching science in a more contextually based unit may have presented differently, however, and is a limitation of this study.

T3 felt her beliefs about the nature of science teaching originated in her daughter's negative feelings about her primary science experience of copying from the whiteboard. Her guided inquiry orientation seems to have developed from combining the pedagogy expected by her school with her longstanding use of investigation in science, supported by her belief in the value of practical experience for students' learning. Her view that one of the purposes of education was to introduce disciplines as potential careers also supported her involvement of students in the practice of science investigation.

The origins of each teacher's orientation to teaching science are complex but appear to link most strongly to personal beliefs rather than an approach specified by the curriculum.

7.4 Use of sociocultural approaches

The sociocultural approaches used by teachers in this study have been analysed individually in Sections 4.2.1, 5.2.1 and 6.2.1, and collectively in Sections 7.2.4.1 and 7.2.4.2. This section uses these analyses to address the third research question which asked to what extent generalist primary school teachers espoused and practised sociocultural approaches generally, and specifically in science. This question arose because the literature suggested analysis of sociocultural approaches seemed to afford more syntactic learning opportunities and may address needs of students commonly not achieving in science more effectively than other approaches commonly used in science education (Anderson, 2007). Research also suggested that primary teachers, when unsure of content, revert to more didactic approaches to teaching (Appleton, 2007; Harlen, 1997).

This question requires a comparison with teachers' general practice that would have necessitated detailed observations of the teaching of other learning areas that was not possible for a single researcher. Interviews with focus students, teachers and observations explored the degree to which each teacher's science teaching reflected their normal practice. Evidence presented in the sections listed above suggests that teachers used their normal pedagogical approach to teach science. However, the degree to which they used sociocultural approaches may have been greater or lesser in other learning areas and a lack of comparative evidence remains a limitation of this study.

The evidence presented suggests that in Case 3, the only occurrence observed of a teacher introducing science content new to her, there was no tendency toward a didactic approach. T3's espoused approach was sociocultural: "We think our kids need to be investigators" (T3/I/22/5). Her practice was sociocultural in almost all aspects.

Examination of the other two teachers' practice reveals that both teachers displayed many sociocultural strategies. Although she espoused the value of discussion and practical experiences for learning, T2's practice was almost developmental in terms of the stepwise introduction of the stages of investigation practised until students were ready for the next stage. Participation in authentic activities and opportunities for enculturation meant that T2's approach was classified as sociocultural. T1 espoused and displayed a social constructivist approach, which fitted with his focus on conceptual development. He espoused beliefs about the importance of learning through participation, but this was not well reflected in his practice. He did, however,

display other sociocultural strategies including creation of a sense of joint enterprise, widely distributed cognition, and use of enculturation and guided participation.

All three teachers used sociocultural strategies to act as cultural brokers enculturating students into what they believed was science. There were several strategies that were underutilised in all three cases, however. Students' opportunities to recognise and practise scientific forms of dialogue such as debate and argument were limited and unsupported. Incidental examples occurred in Case 3, but these were not recognised or developed by T3. All three teachers recognised that science involved contestability of claims, but conjecture and debate based on observation and evidence was not deliberately included as a strategy to teach about science. Rogoff's (2003) learning mechanisms of mutual structuring of participation through structuring using narrative, routines and role plays were not observed. These may not have been part of the teachers' regular practice, or may not have been recognised as useful for science.

A final feature of the teachers' sociocultural practice needs examination. Sociocultural views of teachers as facilitators of border crossings between cultures (e.g., Barker, 2008b) require brokering both ways: into the new culture, in this case science, and from the student's culture. The teachers in this study appeared able to use sociocultural strategies to facilitate entry into many aspects of scientific culture. They were able to establish instructional congruence for students using common New Zealand experiences, T2's use of milk and cereal to develop ideas about control of variables for example. T1's knowledge of local common experiences was reflected in his use of dairying as a context for understanding energy transfer in food chains. However, the lack of bi-cultural emphasis observed when examining the teachers' knowledge of the educational context brings into question the teachers' ability to enculturate Māori students, in particular, into science. Even in Case 3, where T3 regularly incorporated Māori culture and protocols in classroom practice, there was little observed that would assist students identifying as Māori to see connections with their culture in science lessons. This gap may represent lack of knowledge of culturally responsive teaching strategies for science or lack of recognition for their need.

The findings presented in Section 7.2.4.2 showed that a sociocultural approach afforded many syntactic learning opportunities in part because participating in authentic activities, as well as being an opportunity for syntactic learning in itself, created further opportunities for enculturation into science. The nature of science

learning opportunities appeared more dependent on the teacher's orientation to teaching science than on use of sociocultural approaches. Opportunities for substantive learning were limited in Case 2 whereas Class 3 had opportunities for both syntactic and substantive learning. Syntactic learning opportunities could have occurred as part of a social constructivist approach, but T1's orientation was toward developing substantive knowledge.

Teaching in a new content area was not observed to constrain the use of sociocultural strategies in T3's case. The above discussion suggests that while all three teachers made extensive use of sociocultural strategies in teaching science, other sociocultural strategies that may have been useful were not employed. Further, minimal recognition of New Zealand's bi-cultural context in observed science lessons may have provided a constraint to enculturation into science for Māori students. While sociocultural approaches afforded many science learning opportunities, in particular providing syntactic learning opportunities through use of authentic activities, the teacher's orientation to teaching science held greater affordance or constraint with regard to the nature of science learning opportunities provided.

7.5 Student perceptions of their science learning

The final research question asked how students who experienced units implemented by a teacher with a particular set of knowledge and beliefs perceived their science learning.

Evidence from Cases 1 and 2 suggests that students' perceptions of their science learning reflected the nature of opportunities provided, which in turn reflected the teacher's orientation to teaching science. In Case 1, most students gave substantive examples of new or interesting learning and suggested substantive ideas as T1's intentions for their learning. Focus students suggested key concepts such as the significance of producers in food chains as their most important learning; the aspects they said they worked hardest on were also substantive in nature. In Case 2, most students reported syntactic aspects such as controlling variables as new or important learning and suggested T2 wanted them to learn how to do a fair test. Focus students all gave syntactic ideas as their most important learning and as the aspects they worked hardest on.

In Case 3, where both substantive and syntactic learning opportunities were afforded with roughly equal emphasis and abundance, most students identified substantive learning as new or important. More students indicated very positive gains in substantive aspects of learning whereas syntactic gains were described more moderately. More students saw high utility for learning in substantive as opposed to syntactic learning opportunities. Most students also suggested T3 wanted them to learn about organs, although a few recognised syntactic aspects as being among her intentions for learning. Focus students' responses concerning their most important learning were almost entirely substantive; none were syntactic. Their comments suggested that they valued substantive learning. When prompted, focus students were able to identify new syntactic learning. They had difficulty identifying gains in syntactic areas that they said had been addressed in previous science units. Students in Case 1 similarly valued substantive learning opportunities. Their willingness to join with T1 in the enterprise of understanding substantive ideas suggests a common positive disposition among students in Cases 1 and 3 toward substantive learning in science.

These findings are summarised in Table 7.4

Table 7.4: Summary of students' recognition of the content and value of their science learning for each case

Case	Substantive science ideas			Syntactic science ideas		
	Present	Identified	Valued	Present	Identified	Valued
1	√	√	√			
2				√	√	√
3	√	√	√	√	√ (by some)	

That students commonly valued substantive learning over syntactic learning is supported by the finding that in Cases 2 and 3 practical opportunities were seen as highly enjoyable by most students but fewer saw them as useful for their learning. The exception was student designed investigations; these were seen as highly enjoyable *and* valuable for learning where they occurred in Cases 2 and 3. The field trip in Case 1, which was largely a free exploration time, was similarly viewed. When the nature of learning from these practical science opportunities was explored with students, their view of learning was often naively empirical: "it just shows you and you can see it" (C3FS1/I/22/6). Responses to the questionnaire concerning new or important learning included empirical findings in all three cases: that shrimps were transparent, for example. Additionally, focus students in Cases 1 and 3 suggested that observation of the natural world helped their learning because it confirmed

ideas they had read, although Case 3 students suggested exploring organs sometimes changed their conceptions. Conceptual changes described were all easily observable, such as the texture of the lungs. This naïve view of the relationship between empirical findings and science theory suggests students in these case studies saw science learning as acquisition of substantive ideas and that the value of practical science was in confirming or challenging substantive understanding rather than in simultaneously developing syntactic understanding. This is not to say that syntactic learning did not occur, only that it was not well recognised or valued.

Case 2 was the only one of the three studied in which most students clearly identified syntactic aspects as new or important learning. In Case 3, where both types of learning opportunity were afforded, the value with which students regarded substantive science learning dominated their perceptions of learning, despite observations that time and emphasis given in lessons to syntactic and substantive ideas did not appear to privilege one knowledge type over the other. Syntactic learning was a goal of both T2 and T3. In Case 2, this intention was explicit in that the assessed outcome was a report of an independently designed and implemented fair test. The provision of written success criteria made the expected nature of successful syntactic learning clear. Interviews with focus students indicated that practice opportunities and written success criteria were important supports for their learning. In Case 3 syntactic learning intentions were often verbal and general. Although co-construction of syntactic features was common, students in this case may have been less confident about the nature of successful syntactic learning, whether or not they had achieved it, and if it was important to achieve. Measurement of students' learning gains would have allowed further comparisons but was not attempted and is a limitation of this study.

This chapter has presented the findings of cross-case analysis for each research question. In the final chapter the findings for the four research questions are summarised and conclusions drawn. Implications for teacher education and further research and limitations of the study are discussed and ways forward suggested.

CHAPTER 8

Conclusions and Implications

8.1 Introduction

In this chapter, findings for each of the four research questions are presented and discussed in relation to the literature, and implications for teacher education and further research suggested. The limitations for the study are then discussed, followed by a summary of key findings and implications for future research.

8.2 Teacher knowledge and learning opportunities for science

The first question explored the nature of knowledge that generalist primary teachers bring to their science teaching and how that influenced opportunities for learning science. The evidence suggests that these teachers all brought together a broad range of knowledge in order to teach science. Each of the seven knowledges identified by Shulman (1986, 1987) as important for teaching contributed to their implementation of science. These knowledges acted and interacted to facilitate provision of opportunities for science learning and to influence the nature of those opportunities. The teacher's orientation to teaching science, an aspect categorised as part of science PCK, strongly influenced the nature of learning opportunities in each case. Each teacher's orientation to teaching science was enacted through, and sometimes in concert with, the other knowledges.

8.2.1 Using all knowledge domains to teach science

The teachers in this study used each of the teacher knowledges in teaching science. This may explain why Tiplady (2004) represented the knowledge for teaching science as all inclusive. Like the primary teachers she interviewed, these teachers drew on strong general pedagogy and knowledge of context, especially the school community and their students, in implementing their science teaching. The original conception of teacher knowledges by Shulman (1986, 1987) still provides a useful framework for considering all the knowledge teachers bring to their science teaching. Focusing on PCK and content knowledge alone appears insufficient.

Abell's (2007) review of research into teacher knowledge for science suggested that more studies were needed on how general pedagogical knowledge affects the teaching of science. In the cases studied here the different teaching approaches forming part of the teachers' general pedagogical knowledge influenced both the

provision and the nature of opportunities that were afforded. The two cases exhibiting a sociocultural approach afforded more syntactic science learning opportunities than the case where a social constructivist approach prevailed, although this case afforded greater opportunity for substantive science learning. The teachers' strong general management and organisation also impacted on science learning in that students spent considerable time engaged in learning science and were afforded science learning opportunities in the form of feedback and reflection, and through management of classroom discourse. These findings support conclusions that a teacher's enactment in the classroom of existing positive attitudes towards science and strong science teaching knowledge first required development of effective general pedagogical knowledge (Mulholland & Wallace, 2005). The teachers' use of general strategies to teach aspects of science support Appleton's (2006) finding that general pedagogical knowledge fills a gap in science pedagogical content knowledge for primary teachers. Contextual knowledge of students influenced decisions about science topics, the nature of science learning opportunities, and how they were managed. The teachers' general aims, beliefs about vertical curriculum, and orientation to science teaching strongly influenced the nature of learning opportunities.

The usefulness of each of the teacher knowledges displayed in these cases has implications for both initial and in-service teacher education in science. Pre- and in-service primary teachers could be encouraged to consider how each knowledge could contribute to their science teaching. Recognising that they already hold much knowledge useful for science teaching may help build confidence to teach science. Consideration in both pre- and in-service teacher education could be given to development of sociocultural teaching approaches, as findings for this study show this approach facilitated syntactic science learning opportunities which more closely aligned with the direction of the current curriculum than those presented by a purely social constructivist approach. However, the value of the latter for conceptual development should not be overlooked. Teachers capable of using a range of approaches and knowledgeable about the value of each for science learning could make a strong contribution to primary science education.

8.2.2 The influence of orientation to teaching science

Each teacher provided multiple opportunities for students to learn science. The guided inquiry orientation exhibited by T3 provided the widest range of opportunities for science learning, as both syntactic and substantive opportunities were afforded and supported. The academic rigour approach exhibited by T1 provided multiple opportunities to learn higher order principles and concepts, but formal learning opportunities were constrained

to being substantive in nature. T2's process orientation provided multiple syntactic science learning opportunities and supported students to investigate scientifically, but provided only limited substantive learning opportunities. The nature of investigation was restricted to fair testing because of limitations to T2's syntactic knowledge development, as will be discussed in Section 8.3.1.

Kind (2009a) identified that orientation or knowledge of purposes of science education was a component of models of PCK in a number of studies. In this study, orientation to teaching science was included as a component of PCK defined and categorised according to Magnusson et al. (1999). They emphasise that orientation is not characterised by use of particular strategies. Rather it is the *purpose* for which strategies are used that differentiates orientations. So it was for this study. All three teachers incorporated investigation and exploration of the natural world; however, each used it for a different purpose linked to their orientation. The finding that orientation to teaching science so strongly affected the nature of opportunities for learning in science lends weight to theories concerning its overarching role in PCK, influencing science learning goals, choice of instructional activities and assessment decisions (Appleton, 2003; Magnusson et al., 1999).

Each teacher's general aims for education and beliefs about higher levels of the science curriculum influenced their orientation to teaching science to varying degrees. Abell (2007) concludes that a teacher's orientation is not a single entity but "a fluid set of components influenced by a host of issues" (p. 1126). Friedrichsen et al. (2011) recently re-examined Magnusson et al.'s categorisations of orientation to teaching science concluding that these categorisations do not have a sound empirical base, although many researchers had used them as a theoretical framework in investigating science PCK. They proposed reconceptualising orientation toward teaching science as consisting of interrelated sets of beliefs "about the goals or purposes of science teaching, (the nature of) science, and science teaching and learning" (p. 373) and recommended that researchers investigate science teaching orientations from these multiple perspectives.

The concerns expressed by Friedrichsen et al. reinforce the researcher's concerns over the almost circular use of Magnusson et al.'s orientations to science teaching in this thesis. Orientation to teaching science first became obvious in the differing nature of each teacher's practice; each teacher's orientation was easily categorised on the basis of their practice using the descriptors in the Magnusson paper. However, as cases were considered together and the contribution of each

knowledge domain examined in terms of its influence on practice, it became apparent that the nature of practice was influenced by a *set of beliefs* which were also categorised according to Magnusson et al.'s "orientations to teaching science." The descriptors categorising these beliefs, which were so influential *on* the nature of teacher practice, were essentially defined *by* the nature of the practice. The call by Friedrichsen et al. to identify beliefs comprising orientations to teaching science and then to examine their influence on PCK and practice provides greater clarity regarding this construct. The origins of the teachers' orientations to teaching science in this study were discussed in Section 7.3. Table 8.1 uses evidence from previous chapters to describe each teacher's orientation to teaching science in terms of their expressed beliefs in areas suggested by Friedrichsen et al.. Aspects shown in bold were observed to be common features of the associated teacher's practice.

Table 8.1: Teachers' beliefs relating Magnusson et al.'s orientation to teaching science (1999) to components suggested by Friedrichsen et al. (2011)

Orientation (according to Magnusson et al., 1999)	Beliefs comprising orientation to teaching science (according to Friedrichsen et al., 2011)		
	Beliefs about goals or purposes of science teaching	Beliefs about (the nature of) science	Beliefs about science teaching and learning
T1 Academic rigour	<p>General aim was to prepare students for secondary education by becoming independent learners through use of information technology. Suggested frequently in science lessons that he wanted students "to understand."</p> <p>Intended goals for the unit were stated as knowledge of tides and knowledge of communities including eating patterns.</p> <p>Developing scientific skills and attitudes was suggested as an important focus for science education.</p> <p>Wanted students to know that science was a process, contestable and not a fixed body of knowledge.</p>	<p>Believed science is not a fixed body of knowledge. It changes as technology develops. Science ideas are contestable. Science involves experimenting and researching.</p> <p>Viewed and used substantive science knowledge to explain the world as a series of interrelated systems that all worked together.</p>	<p>Students enjoy and learn from practical activities. Students' interest and engagement contribute to learning.</p> <p>Students need to find out knowledge for themselves building on existing ideas. Students should have an accurate written record of science ideas covered. Students at Year 7 and 8 enjoy engaging with complex science ideas.</p>

Orientation (according to Magnusson et al., 1999)	Beliefs comprising orientation to teaching science (according to Friedrichsen et al., 2011)		
	Beliefs about goals or purposes of science teaching	Beliefs about (the nature of) science	Beliefs about science teaching and learning
T2 Process	<p>Aimed to prepare students well for secondary school. Wanted them to think critically about the world around them.</p> <p>The above aims were seen as achievable through learning fair testing processes.</p> <p>Thought science education should raise awareness of potential careers.</p>	<p>Believed fair testing was significant to all science and underpinned future science education.</p> <p>Science investigation involves empirical testing and observation of the natural world. Collegiality is important in scientific endeavour. Useful scientific investigations develop from curiosity and wondering. Science involves critical consideration of claims. Scientific hypotheses are reasoned, cognisant of current scientific thinking and able to be tested. Scientific data should be measured and recorded accurately and in an organised manner, and that validity of results is important in scientific endeavour. Fair testing involves selection of an independent variable which is changed in ways allowing the effects of the change on the dependent variable to be measured, whilst other variables are controlled.</p>	<p>Modelling and scaffolding were seen as the most useful aspects of her practice with regard to learning. Believed students learned through discussion. Practical work was seen as engaging and motivating.</p>
T3 Guided Inquiry	<p>A general aim was that students become independent and self-managing learners with their own interests.</p> <p>A purpose of education was to introduce a range of disciplines that may spark interests or careers.</p> <p>Aimed to build students' perceptions of science as a discipline through her science teaching.</p> <p>Preparation for secondary schooling was a consideration.</p>	<p>Science investigation involves exploring and testing ideas in the natural world and requires rigour and accuracy in gathering and recording data.</p> <p>Science must account for all natural occurrences: there are no 'wrong' results. Science theories are contestable. Science investigation takes many forms. Experiments can be controlled in different ways. Interpretation and theorising are important features of science.</p> <p>Features of scientific investigations include being planned, sharing ideas, working together and being flexible and adaptable.</p>	<p>Learning is enhanced by students answering their own questions. Students learn through practical experience. Participation in discussion is important for learning as is participation in authentic science investigation and practices.</p>

In each case the outworking of the teacher's aims were mediated by their beliefs about the nature of science and science teaching and learning in influencing practice.

The table shows that the beliefs expressed by these teachers were a diverse mixture of the three aspects identified by Friedrichsen et al. (2011). The teachers' general aims for their students were an important influence and were enacted through their science teaching. Beliefs about the nature of science were also influential on the nature of opportunities provided in all three cases. T1 expressed beliefs about goals for science education concerning the nature of science processes and the contestability of science knowledge that were not obvious in his practice. Similarly, while some of the beliefs T2 expressed about the nature of science were explicit in her practice, others were not. The teachers' expressed beliefs about the nature of science teaching and learning were all reflected in their practice. Many of these beliefs about science teaching and learning were components of the teachers' beliefs about learning in general and were part of their general pedagogical approaches, for example beliefs concerning the value for learning of participation in discussion.

Friedrichsen and Dana (2005) found for secondary biology teachers that many of the goals comprising their orientation to science teaching were general and included preparation for life, as in this study, and concerned the next educational step in students' education when that was imminent, also as in this study. T1's goals that students should understand science as a process and science knowledge as contestable may have been what these researchers termed a peripheral goal that was less visible in practice than central goals, or, given the context of the study, these goals may have had less opportunity for enactment. Alternatively, T1 may have been unclear as to how to convey these ideas; his PCK for syntactic science teaching may have been lacking. This aspect was not pursued at the time of study. Friedrichsen and Dana also found that teachers' goals varied for different classes and levels. The cases in the present study were limited to one unit of science. The teachers' goals, and therefore orientations, may have been different in different situations.

The analysis of these teachers' beliefs in conjunction with their practice will contribute to research described as necessary by Friedrichsen et al. (2011) into the influence of teacher beliefs with regard to orientation to teaching science and teacher practice. The influence of the teachers' orientation to teaching science in the

development of content and pedagogical content knowledge (Sections 7.3 & 8.3) adds further weight to the contribution of this study concerning the role of teachers' beliefs in science teachers' practice.

Each teacher's orientation was very influential on the opportunities for science learning afforded to their students but comprised an individual set of personal beliefs about the nature and purpose of science and science teaching largely independent of the direction and purposes suggested in the relevant curriculum. A recent document discussing the future of science education in New Zealand suggests that "the clarification of a shared understanding of the purpose of science education is essential if the enacted curricula in schools are going to meet the needs of students of different stages of education" (Office of the Prime Minister's Science Advisory Committee, 2011, p. B-57). Related documents suggest possible purposes and characteristics for different stages of education (Bull, 2011; Bull et al., 2010). Findings from the present study would suggest that while such intentions may be beneficial, taking cognisance of the complex set of beliefs that appear to influence practice would be wise if change is to be effected. Findings also suggest that assisting teachers to understand the nature of higher levels of the curriculum may be beneficial as these teachers' beliefs about vertical curriculum impacted on the enactment of their aims.

8.3 Development of knowledge for teaching science

The second question investigated how generalist primary teachers developed the knowledge they needed to teach science. Syntactic and substantive science content knowledge and new PCK, topic-specific activities that work and assessment tasks, were intentionally developed through accessing resources and collaboration with other teachers. Further PCK, including instructional strategies for topic-specific substantive knowledge and more generic syntactic PCK applicable across topics, was found to develop through reflection and repetition. Means of developing syntactic content knowledge were not as readily accessible as sources of relevant substantive knowledge. General pedagogical knowledge was often used to teach content knowledge, thus contributing to development of new PCK, as did engaging students in practical science. Curriculum documents may have guided the nature of content knowledge development by indicating important general concepts and principles. Orientation to teaching science, or the beliefs comprising it, influenced the nature of PCK and science content knowledge that developed. These findings were summarised in Figure 7.1 (p. 224) and are discussed in relation to the literature in following sections.

8.3.1 Science content knowledge and its development

Intentional development of content knowledge was also observed in Tiplady's (2004) study of New Zealand primary teachers. Traianou (2006) had similar findings. Both found primary teachers had developed content knowledge through reading and talking with other teachers. The teachers in the present study also drew on their background content knowledge, as identified by Tiplady.

Sources of substantive and syntactic knowledge were not equally accessible to the teachers in this study. The teachers seeking substantive knowledge did so from multiple sources in the form of books and information from the internet. The teacher who wanted to develop her syntactic knowledge attempted to do so by accessing the few connections she had with the scientific community and using reifications of practice in the form of science fair guidelines and exhibits. Despite study of the nature of science being indicated by New Zealand curriculum documents since 1993 and currently compulsory study for Years 1-10, support provided by the MOE has mainly been in on-line form and was not accessed by teachers in this study. Hodson (2009) suggests that teachers need to be immersed in science in order to develop syntactic knowledge. His review of the research into development of syntactic knowledge by teachers concurs with that of Abd-El-Khalick and Lederman (2000): an explicit and deliberate approach is generally more effective. Opportunity to reflect on personal views seems important, as does the inclusion of both context free and context embedded approaches (Clough, 2006; Heap, 2006; Hodson, 2009; Khishfe & Lederman, 2006). That reifications can be useful where participation in a community of practice is not possible appeared true for T2 (Wenger, 1998). T2 identified and adopted many valuable aspects of syntactic knowledge from reifications of practice. Her lack of knowledge about the diversity of scientific forms of investigation reflected gaps in these reifications. Wenger suggests participation in practice can clarify confusions caused by misunderstandings, or in this case omission, in reifications. This study suggests that where participation does not occur, confusions and omissions persist.

Evidence suggests the curriculum may have been an influence on knowledge development. T2's limitation of science investigation to fair testing reflected the focus of the then current curriculum. T1's and T3's substantive knowledge of general concepts and principles reflected the direction of the 1993 science curriculum (MOE, 1993a). Arzi and White (2008) showed that school science curriculum strongly influenced teachers' science content knowledge development over time. Regardless of its origins, knowledge of general concepts and principles was useful in focusing and guiding the direction of science teaching and learning in these cases.

8.3.2 Science PCK and its development

Intentional development of PCK by teachers in this study occurred through use of activities that work as identified by Appleton (2002), but also through teachers rehearsing activities together before their use in the classroom. Daehler and Shinohara (2001) suggest both PCK and associated content knowledge can arise from teacher discussion. Kind (2009a) found a number of studies supported collaboration as a means of nurturing PCK development for new science teachers.

PCK was also observed to develop in two teachers in this study through a process of reflection and repetition. Engaging students in practical science exploration and investigation enabled PCK development for one of these teachers. The process of reflection and repetition exhibited supports the cyclical process of pedagogical reasoning Shulman proposed for the transformation of knowledge for teaching (1987). Kind (2009a) in her review of research evidence concerning PCK, identified three key components common in development of PCK: classroom experience, possession of good science content knowledge, and having “well adjusted emotional attributes” (p. 199). In the latter she includes a “willingness to improve and reflect” (p. 185). Appleton (2006) identified confidence to begin teaching science as key to PCK development. In her own research among novice secondary teachers teaching outside their science specialisation, Kind (2009b) found a confident group, not overly concerned by the quality of their content knowledge, who identified that providing appropriate activities was key to supporting student learning. Confidence to engage students with science investigation, despite the nature of personal content knowledge, characterised T2 and T3 in the present study, and enabled the process of PCK development over time through reflection and repetition.

A major debate in the literature is whether PCK development is integrative, whereby teachers draw together knowledge from other domains as needed, or is permanently transformed from content knowledge and other domains to exist as a domain in its own right (Gess-Newsome, 1999). Findings from this study suggest that, as observed by Appleton (2006), both processes occur. T3 was observed teaching new material “on the spot”, implementing new content knowledge using general pedagogical knowledge. Reflection and repetition appeared to turn this combined knowledge into established PCK; the strategy was refined and reused for subsequent groups. T2 was observed using activities she had found useful previously for teaching a particular science aspect, i.e., drawing on existing PCK. At other times she was observed applying new general pedagogical knowledge to teach a syntactic science idea. A process of reflection was observed as she

reviewed its success. These observations provide support for both integrative and transformative processes for PCK. Certainly there was evidence of use of knowledge for science teaching that had developed over time and through classroom experience (Kind, 2009a). Some of this knowledge depended on substantive content knowledge but some was a type of knowledge useful for supporting practical science and student investigations that grew out of the teachers' aims, their beliefs and knowledge of syntactic aspects of science, and their general pedagogical approaches. This PCK could be classed as syntactic PCK as described by Smith (1999): useful in facilitating understanding of the nature of science.

8.3.3 Orientation to teaching science and its influence on knowledge development

Friedrichsen et al. (2011) suggest there is evidence to support Magnusson et al.'s (1999) placement of science teaching orientations as filtering or shaping the content and development of the other PCK components. This study supports the findings of Nilsson (2008) that orientation to teaching science shapes aspects of PCK. In all three cases beliefs about the goals and purposes of science education, the nature of science, and science teaching and learning influenced the assessment aspect of PCK in terms of dimensions of assessment. Beliefs in all three categories guided the nature and selection of activities, influencing development of PCK. These beliefs also affected the development of science content knowledge as teachers intentionally sought the kind of knowledge their orientation required. The beliefs demonstrated by the teachers seem to have developed over time from an individualised mix of experiences and assumptions. Previous studies have found that some pre-service teachers' orientations change over time whereas others' remained constant and teachers developed their learning in response to their orientation (Anderson, Smith & Peasley, 2000). Bryan and Abell (1999) suggest that explication of beliefs, in conjunction with reflection on practice, can produce perturbations that change beliefs about the nature of science teaching.

8.3.4 Implications of findings about knowledge development

Knowing that useful substantive content knowledge for a particular topic can be found by reading and using the internet may be encouraging for primary teachers. Locating and critiquing information sources useful for different science topics could form part of initial science teacher education. Findings suggest that supporting teachers to identify general concepts, principles and relations relevant to a topic may be useful. Such is the focus of the *Building Science Concepts* books provided by the MOE. An evaluation of their use would provide insight as to whether or not this form of

knowledge generally supports primary science teaching. However, given the findings of this study and the focus of current curriculum on scientific literacy, a focus on substantive knowledge development seems less critical than development of syntactic science content knowledge. There are several attempts to provide access to such knowledge currently underway: the *Science Learning Hub* that provides examples of New Zealand scientific research for upper primary and secondary contexts has recently been developed (<http://www.sciencelearn.org.nz/>). Lists of ideas about the nature of science have appeared on the MOE's teacher support website (<http://scienceonline.tki.org.nz/Nature-of-science>). The Royal Society of New Zealand manages a project enabling primary teachers to work in a science-based organisation for six months to experience first-hand the nature of science. An implication of findings of this study is that research into effective ways of developing primary teachers' syntactic knowledge is urgently needed if they are to guide students toward an appreciation of the nature of science: what science is, how it generates knowledge, and how it can contribute to society. The reifications of scientific practice currently provided may not be sufficient, particularly when unsupported by professional development opportunities concerning their availability and application.

Different types of PCK were developed by the teachers in these cases. While instructional strategies useful for teaching topic-specific substantive knowledge were useful at the time, the nature of New Zealand primary science teaching is such that this PCK may never be useful again because teachers move on to address new topics. However the idea that repetition produces useful PCK could be useful as schools often manage their science teaching so that one teacher leads a particular activity with different classes or groups as part of a rotation. Recognising that this strategy has benefits in terms of teacher knowledge development while also reducing the load for individual teachers may help build teachers' confidence to teach science. Understanding the benefits of collegially supporting each other to teach science and the usefulness and application of activities that work in primary science could also build confidence. Syntactic PCK could be worthwhile to address in both initial and in- service science teacher education; for example, teachers could discuss and practise evaluating possible science contexts for their potential for student investigation. The diverse origins of beliefs that were so influential on the nature of learning opportunities and the PCK and content knowledge that was developed by the teachers indicates that research into their development and change is required. The literature suggests that explication and reflection may be important (Bryan & Abell, 1999). Reflection on science teaching and learning was

significant in PCK development; its use and value for future science teaching could be explicitly fostered in initial and in-service science education.

Kind (2009a) suggests that a transformative view of PCK is useful for teacher education as it can make explicit strategies for developing the complex and abstract ideas involved. For primary science education that is focused on developing syntactic as well as substantive science understanding, a transformative view would also be useful: PCK for both substantive and syntactic science teaching could be highlighted as indicated above. An understanding that PCK can develop from other knowledge domains, is also important for teachers and teacher educators. Hashweh (2005) suggests that planning for science is one way of integrating knowledge from different domains that leads to PCK development. Providing opportunities in primary science teacher education to plan for, and reflect on, teaching a particular science topic for a particular group of students, deliberately considering and including knowledge from a range of domains, could begin the process of PCK development for science and support the process of ongoing knowledge creation that appears to happen with reflection on experience in teaching science.

8.4 Sociocultural approaches to science teaching

The third research question explores the extent to which these generalist primary teachers espoused and practised sociocultural approaches generally, and specifically in science. All three teachers appeared to use their usual teaching approach to teach science, although evidence was limited. Two of the three teachers used a sociocultural approach to teach science and the third applied a social constructivist approach but incorporated sociocultural strategies. It was anticipated from the literature that teaching a new topic may have resulted in didactic teaching (Appleton, 2007; Harlen, 1997; Loughran, Mulhall & Berry, 2008). This was not what was observed. The teacher who taught an unfamiliar topic made most use of sociocultural strategies. These findings are limited, as this teacher was confident in teaching science and held strong beliefs about teaching approaches. Other teachers may well teach more didactically when teaching new science topics.

Sociocultural approaches afforded many opportunities for syntactic science learning. When combined with a guided inquiry approach they also afforded substantive opportunities. Orientation, or beliefs about the purposes and nature of science and science teaching, moderated the nature of learning opportunities provided by sociocultural approaches. Participation in authentic activities enabled many acts of

enculturation into scientific practices and values. Widely distributed cognition, including the use of natural objects as thinking tools, afforded a wide range of science learning opportunities. Use of interactive dialogic class discussion contributed to a sense of joint enterprise and facilitated co-construction of features of scientific texts, practice, values and concepts. Use of staged tasks, examples of expert practice and structuring of direct interactions facilitated enculturation, although sources of examples of expert practice were limited with regard to the processes of science; the two teachers who included teaching about scientific processes used their own examples of expert practice.

Stories about science were not used and neither was there deliberate enculturation into the use of scientific forms of discourse such as debate and argument. Use of science stories may not have been a familiar pedagogy, or may reflect a lack of syntactic knowledge useful for teaching. Despite all three teachers recognising science knowledge as contestable, it was not seen as contestable in their classrooms and ways of contesting such knowledge were not developed. Another common gap was the absence of use of contextual knowledge relating to New Zealand's bi-cultural heritage. While the teachers each drew on contexts and experiences familiar to their students in enculturation into science, very little reference was made to Māori culture in science.

Sociocultural approaches afforded syntactic learning opportunities but did not necessarily offer the substantive learning opportunities afforded by the social constructivist approach employed by T1, unless combined with guided inquiry. The teachers' application of approaches appeared as a result of personal beliefs about learning rather than purposeful application of learning theory. One implication of findings is that critically evaluating the nature of sociocultural and other approaches and their application in science education may be useful as part of initial teacher education. Research into such interventions would be informative. While sociocultural approaches hold potential for the cultural border crossings needed to reach all students to occur (Aikenhead, 1996; Anderson, 2007; Barker, 2008b), the findings above suggest that teachers need to have and be able to apply syntactic knowledge as well as cultural understanding in science for this to happen. These teachers were unaware of recent moves in science education toward both narrative-based teaching approaches (Barker, 2002; Irwin, 2000) and use of scientific forms of discourse (Keogh et al., 2003; Osborne et al., 2001). Given the lack of professional support for primary science in recent years this is unsurprising (Bull, 2011; ERO, 2010). Reasons for the teachers' lack of inclusion of culturally responsive teaching

in science were not explored in this study. There have been moves to support teachers with culturally responsive teaching such as Te Kotahitanga (<http://tekotahitanga.tki.org.nz>), evaluation studies reporting some success (Savage et al., 2011). This MOE supported initiative targeted secondary schools. Little support has been provided for primary schools especially with respect to science. Teachers' beliefs and practice concerning culturally responsive teaching as pertaining to science are an area for further research.

8.5 Students' perceptions of learning in science

The final research question in this study asks how the students of teachers with a particular set of knowledge and beliefs perceived their science learning. As Abell (2007) concluded, studies of the influence of teacher knowledge on student learning in science are few, thus highlighting an important contribution of this study to the field of teacher knowledge within science education research. For reasons explained in Chapters 1 and 3, this study focused in particular on the influence of teacher knowledge on students' perceptions of their learning with regard to syntactic and substantive outcomes. Substantive science learning was identified by students where this had been the focus of learning opportunities because of the teacher's orientation, and similarly for syntactic learning. When the teacher's orientation, or belief set, afforded both types of learning opportunity, only substantive ideas were identified as important or new learning. In both cases where they were common, practical opportunities were seen as enjoyable rather than valuable for learning, although student-designed investigations were both enjoyed and valued. Students in all three cases held naive views of the empirical nature of science and valued the substantive learning gained from practical opportunities. The only case in which gains in syntactic learning were readily identified by students was where syntactic learning was the only intended form and they had opportunity and incentive to compare their syntactic learning with set expectations; the nature of expected syntactic learning was highly explicit and there was apparent value for students in attaining it.

Studies suggest scientific inquiry appears useful when syntactic considerations are fore-fronted for learners, facilitation is given to reflection about the nature of science, and the inquiry is viewed as a context for learning about the nature of science, not a goal in itself (Abd-El-Khalick & Lederman, 2000; Hodson, 2009). Cases 2 and 3 presented examples of school scientific inquiry for primary students as close to authentic science inquiry as possible (Schwartz & Crawford, 2004): students were

actively involved in scientific inquiry processes and meaning construction, but with an appropriate level of support (Schwartz, Lederman & Crawford, 2004). Students in this study enjoyed and valued learning from this form of practical science, supporting its development in primary schools as a context for syntactic and substantive science learning. T3 had an explicit approach to teaching about the nature of science through inquiry; she drew learners' attention to syntactic science ideas "through discussion, guided reflection, and specific questioning in the context of activities and investigations" (Schwartz et al., 2004, p. 614). She also assessed students' syntactic learning and encouraged their reflection on resulting feedback, yet her students more readily identified substantive ideas as new or important learning. Findings suggest that these students tended to view substantive ideas as the natural outcome of science education, and when presented with both syntactic and substantive opportunities, more readily recognised learning goals aligned with their expectations. These views may impact on surveys that suggest New Zealand primary students learn little about science at school (Crooks et al., 2008). That many students perceived practical science as fun but not valuable for learning suggests further research into New Zealand primary students' expectations concerning learning in science would be beneficial. If such views are common, since syntactic learning is an overarching aim of the current New Zealand science curriculum, teachers will need to develop ways to make the relevance and purpose of syntactic learning goals more explicit for students. The strategies employed by T2 were useful for the science fair unit, but may not be the most effective for other contexts. T3's strategies, while meeting the pre-requisites suggested in the literature, were not successful in that students did not recognise or value syntactic learning. The need for further research into the development of syntactic science PCK appropriate for New Zealand primary students is another implication of these findings.

8.6 Limitations of this study

While this study contributes to understanding about the nature of teacher knowledge and beliefs as used and developed by primary science teachers in New Zealand, there are a number of limitations. The study comprised a small purposive sample of teachers from a region that was geographically accessible to the researcher. The teachers were selected because of their longstanding position in a school known to teach science regularly and in a well regarded way at Years 7 and 8. The cases were all from schools in middle to high socio-economic areas. Cases comprised the teaching of only one unit of science. These findings are not generalisable to other teachers in other contexts, but do suggest useful areas for further research in other contexts.

There are limitations to findings concerning students' perceptions of their learning. Although whole class questionnaires and interviews with focus students provided multiple sources of data, the data only afforded students' *perceptions* of their learning; findings cannot be interpreted as representing students' actual learning gains. Data were collected at the end of each unit so only provide immediate rather than long-term perceptions. The tools used for data collection relied on students' ability to articulate their ideas verbally or in written form. In each case there were several students who struggled to convey written responses and at least one focus student who gave limited verbal responses. The questionnaire, while read to students one question at a time to facilitate comprehension, was long, so that students may have given later questions less consideration than those appearing earlier. The questionnaire was also administered in each case by a different person – the researcher in Case 1, a student teacher in Case 2, and T3 in Case 3 – which may have affected student responses. While open general questions allowed students to provide their own responses, more focused questions concerning the nature and focus of activities and teacher actions relied on the researcher's interpretation of classroom events. The teacher selected the sample from which focus students were drawn in each case. They were asked to select "average" students rather than those known to be knowledgeable or enthusiastic about science, but their selection of students may have been biased.

The impact of having a researcher who is also a university lecturer in science education provides a significant level of intrusion for both teachers and students, as does knowing that lessons are being audio-recorded and documented. Attempts were made to intrude as little as possible through use of a small digital recorder with a powerful microphone. Collegial and positive relationships with teachers and students were established early and the researcher's presence appeared to be rapidly taken for granted; however, the presence of the researcher, her microphone and note taking may have had an effect on behaviours and practice.

The final set of limitations concern the interpretive or qualitative paradigm and research design. Because of personal and school circumstances, this research was carried out by a single researcher part time over a number of years; data collection was limited by researcher availability and school and classroom programmes. Transcription and analysis of data were completed well after data collection. While teachers were offered the opportunity to check and amend transcriptions of interviews and lessons, none did. Participant checking of the researcher's interpretations following analysis would have strengthened the design, but was not

feasible because of the lack of immediacy of final analysis. The findings are reliant on the interpretations of a single researcher and therefore subject to her biases. While use of multiple sources of data, application of clearly defined frameworks and repeated checking and cross-checking of analysis of transcripts, observations and field notes strengthen the validity of findings, other interpretations are possible. The position of the researcher was made clear in Chapter 3 in order to address issues of reflexivity, but the interpretations presented are still influenced by her beliefs and experiences and must be seen in that light.

Finally, consideration needs to be given to how well a teacher's practice reflects the nature of their knowledge and beliefs. In this study teachers were interviewed and their practice examined in order to see the outworking of beliefs and knowledge as well as espoused beliefs, but the degree to which practice reflected teacher beliefs and knowledge is a difficult consideration and must necessarily be contingent on a number of contextual and personal factors. Discussions with teachers about intended learning before lessons and about actual events and reasoning behind teaching decisions after lessons were used to try and illuminate this aspect, but use of stimulated recall techniques and participant checking following more immediate analysis of data would have strengthened findings.

8.7 Summary of key findings and implications

In summary, the evidence presented suggests that:

- The New Zealand primary teachers in this study drew on each of the defined teacher knowledges in facilitating learning opportunities in science.
- A major influence on the nature of the learning opportunities afforded in each case was the teacher's orientation to teaching science, considered to be part of PCK and comprising a complex set of personal beliefs about aims and purposes for education generally and for science, beliefs about the nature of science and science teaching and learning.
- Teachers intentionally developed substantive and syntactic content knowledge and some forms of PCK for teaching science. Further PCK developed through a process of reflection and repetition from use of general pedagogical strategies to teach science content. The teacher's orientation to science teaching, or the beliefs of which it is comprised, influenced the nature of knowledge they developed.

- Examples of expert practice and other sources of syntactic science knowledge were not as readily available to teachers as sources of substantive science knowledge. The knowledge developed reflected omissions in the reifications of practice that were accessed.
- All three teachers used a wide range of sociocultural strategies in teaching science. Sociocultural approaches provided more syntactic learning opportunities than the social constructivist approach exhibited, but orientation to teaching science was also influential. A guided inquiry orientation afforded both syntactic and substantive learning opportunities.
- Teachers made little use of science narrative, scientific forms of discourse and knowledge of New Zealand's bi-cultural context in enculturation of students into science.
- Students' perceptions of their learning reflected the opportunities afforded by their teacher's orientation to teaching science, except in the case where both syntactic and substantive learning opportunities were afforded. In this case students' perceptions of new or important learning were substantive. Responses suggested a tendency for students to recognise and value substantive over syntactic learning opportunities.

A major implication of these findings is that further research into the development and influence of teachers' orientation to teaching science, their beliefs about the purposes and nature of science and science teaching, is needed if outcomes contributing to understanding the nature of science and its contribution to society are to be achieved. How firmly fixed are these beliefs? Do they change in response to professional development? If teachers are clear about the purpose of science education as suggested in a curriculum document will this change their practice or will personal beliefs still hold influence?

Findings about students' perceptions of their science learning need further investigation. What are primary students' conceptions generally concerning what they should learn in science? Does this impact on their perceptions of how much they learn in science? What do they find stimulating in science?

A final area for further research is the nature of syntactic and associated PCK that will best support New Zealand primary teachers to build for their students understanding of what science is and how it works, as well as how such knowledge is best developed in teachers. Professional development in this regard is currently

under-researched, uncoordinated and haphazard at best (Bull, 2011; ERO, 2010). Findings from this study suggest that it is not easy for teachers with little connection with, let alone participation in, the world of science to access or develop syntactic knowledge; teachers relied on their background knowledge or attempted to access appropriate knowledge with limited success. In the main they taught syntactic knowledge using their general pedagogical knowledge, with mixed results given student perceptions of the resultant learning. Considerable research exists into the development of understanding of the nature of science. The nature of teaching that supports students' development of this knowledge is a growing research area (Hodson, 2009). Yet the research fields of teacher knowledge and nature of science appear separated in the literature. Abell (2007), for example, did not include research about the nature of science in her extensive review of science teacher knowledge, although syntactic science knowledge was acknowledged as part of subject matter knowledge. Syntactic PCK, knowledge useful in teaching syntactic science content, is not included in common models of PCK (e.g., Cochran et al., 1993; Magnusson et al., 1999). Research into the teaching of the nature of science does not usually address other aspects of teacher knowledge required for science teaching. While syntactic learning is key in developing science literacy, agency in dealing with the natural world is also a useful and expected outcome of science education (Anderson, 2007). Teacher knowledge frameworks in current use do not adequately address the knowledge of culture and culturally responsive teaching strategies that are needed if science is to reach all students (Anderson, 2007). Figure 8.1 is therefore proposed as a revised framework for teacher knowledge incorporating these aspects. Based on the findings of this study, it adds to those previously proposed in order to support primary science education in the New Zealand context. Further research would test the usefulness of the framework, strengthen and develop it.

Figure 8.1: A framework for interconnected and active teacher knowledges to support primary science education in a New Zealand context⁽¹⁾
 Green shading indicates aspects pertaining particularly to science; NZC refers to The New Zealand Curriculum (MOE, 2007)

⁽¹⁾ The headings used in this framework are from Shulman (1987)

8.8. Concluding words

This thesis began with an unsupported proposition that New Zealand primary teachers brought more to their science teaching than poor content knowledge. Findings show that, while there were areas for development, these teachers each brought much that was useful: a wide range of teacher knowledge that contributed to providing learning opportunities in science, confidence to teach science and investigate with their students, a willingness to find for themselves the knowledge they believed their students needed to know in science, a desire to help their students gain understanding about the world and what science is like, and a strong ability to use their general pedagogical knowledge to teach a range of scientific ideas.

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Appendices

Appendix A: Observation sheet

School: Date: Day: Time: Class Numbers: Girls: Boys: General Demeanour:

Time	Activity	Group Type*	Engagement				
			Student 1@	Student 2@	Student 3@	Student 4@	Class#

* 1 individual; 2 pairs; 3 small groups (3-6); 4 large groups (7 or more) 5 whole class. T = teacher selected; S = student selected

measure of on task behaviour 1= less than $\frac{1}{4}$ class; 2= $\frac{1}{4}$ - $\frac{1}{2}$ class; 3= $>\frac{1}{2}$ - $\frac{3}{4}$ class; 4= $\frac{3}{4}$ -all

@ measure of individual on task behaviour: 1= hardly engaged; 2= engaged for less than half time; 3= engaged for most of time; 4 = engrossed

Appendix B: Teacher interview schedule

Prior to Unit

About teaching background

Can you tell me about your teaching experience:

How long have you been teaching?

Did you train in NZ?

Experience in different schools?

Any experience in leadership?

Any special expertise?

About learning:

How do you think students at year 7 and 8 learn?

What do you do as a teacher that helps that learning to occur?

What things do you think teachers need to do to help their students learn?

What kinds of things do you think Yr 7& 8 students need to learn?

Is there special knowledge that you draw on as a teacher to help your students learn?

About science teaching in general.

Do you enjoy teaching science? Why/why not?

Do you have a background in science? (if so what?)

What is your experience in science teaching?

How important do you think it is that children learn about science at school?

What do you think children need to learn about science during primary school?

Do you have particular aims for science for your Year 7/8 students? (Why?)

How do you go about making that happen?

Any particular content they should learn? Skills?

What about science itself: what do you think they need to know about that?

Any thoughts about *how* children learn about these kind of things?

What do you see as your role in science teaching at this level?

Are there any particular kinds of learning experience that you use that you think helps children with learning science?

How do you see the role of practical work?

Do you use book work and writing in science? How? Why?

Do you use worksheets for science? What for? Why?

Are there any other kinds of things you use in science? What for? Why?

What about reading?

Are there any resources you find useful in general for science? Anything you use a lot? Why? How do you use them?

How does science fit with other things you do with your class?

(other curriculum areas?)

Is there anything that is different that you think about when you start to plan for science?

Are there any considerations you have about this particular class group when you plan for science? (Why?)

Is there anything else you want to tell me?

C. About school factors

How does science happen in your school? What are the school expectations for science? (long term plans, policy etc)

Is there a programme for regular school review and how does it happen for science? Does this impact on the way science is implemented in the school?

Is there a school wide assessment regime? How does it work for science?

What support is there for science? I am thinking about such things as planning support/resources accessibility of equipment/timetabling/budget/professional/collegial support.

How often do you teach science? What affects that?

Does science happen regularly in most classes at the school? Why? Why not? What affects whether it does or not?

Are there any aspects about the school or community in general that influence what you do in science? Any parental views or issues that you think affect science delivery in any way?

Are there factors in the school and or its community that affect the delivery or effectiveness of science education at Yr7 & 8 level in particular?

D. About this unit of work

Do you have a particular reason for doing this unit at this time?

Do you think the children will enjoy it?

Are there any considerations you have about doing this topic with this particular class group?

If there is a written plan: What was involved in developing this? What did you do and consider?

If not: What do you do and consider when planning each session or sequence? (Planning steps...? Resources? Equipment?)

Are there any experiences that you think are particularly important or significant?
Why? What do you want the children to get out of doing this topic?
Do you have any ideas you consider are really important for them to develop: big ideas, concepts? Any particular skills or understanding of science you'd like for them to develop? Why?
Is there anything you think they may find tricky?
Why? How do you know?
Does that affect what you've planned to do with them? (How?)
Is there anything you'll be watching for in particular? Why?
Do you have any assessment planned? What? Why?
What is the focus for assessment?
Anything else you want to tell me?

Before a lesson

What are you aiming to do today?
What do you think will be the key part of the lesson?
Are there any parts you think the children will particularly enjoy or engage with?
What are you expecting the children to learn today? (skills? content?)
Anything else I need to know?

After lesson

Did you achieve what you wanted to? How? Why not?
Which parts do you think the children enjoyed?
Engaged with?
Learned from? (what?)
How do you know?
Were there any things you changed? Why? Consequences?
How did you know to/about...
Anything difficult?
Anything unexpected?
Any other comments?

After unit

In general how did you think the unit went?
Do you think the children enjoyed the topic? Any bits in particular? How do you know?
How well did they engage with it? How do you know?
Are there any experiences that you think were particularly important or significant? Which? Why?

Were there any aspects that caught children's imaginations? What did they do in response? What do you think caused this?

Were there any differences between what you'd originally planned to do and what you actually did? What was involved there?

Did the children get what you wanted out of the unit? What was that? How do you know? Which experiences do you think helped? Is there anything in particular that *you* did that you think helped? Anything else that you think influenced what they learned?

Was there anything you hoped they'd get that didn't come over so well? What? How do you know? Why do you think that was?

Is there anything the children found difficult?

Why? How do you know?

Did that affect what you did in anyway?How?

Before the unit you said you'd be watching out for..... What happened about that?

What happened about assessment? What did the assessments tell you? Anything you'll follow up from that?

Is there anything else you'd like to tell me...?

Appendix C: Focus student interview schedule

Prior to Unit

About science in general

Do you like science?

Do you do much about science by yourself for your own interest? (tv programmes, inventions, experiments?)

Is anyone in your family interested in science or doing things to look after the environment?

Do you like doing science at school?

How important do you think it is that children learn about science at school? Why?

What do you think students your age need to learn in science?

Is there anything you think they need to learn to *do* in science?

How do you think they learn these things?

What do you think teachers should do that would help students your age learn these things?

What do you think about doing experiments and practical stuff in science? Do you do much of that? How important is that? Do you enjoy it? Do you think you learn from it? What kind of things? How? (apply same probes to next two questions)

What do you think about book work and writing in science?

Do you use worksheets in science much?

Is there anything else you do in science that helps you learn? How does it help?

How does science fit with other things you do at school: do you look at the same topic in other subjects at the same time or is it separate? Do you learn different things in science that you don't learn in other subjects?

Is there anything about science that's different to doing other subjects? Does your teacher teach it differently or much the same?

About school factors

How often do you do science at school?

Are there things about your school or things that happen there that make it more difficult for you to learn science? Things that make it easier?

About this unit of work

You're going to be doing a topic in science about..... What kinds of things do you know about that already?

Do you think you'll like doing it? Why/why not?

What kinds of things do you think you might be doing?

What sorts of things would you *like* to do in this topic?

What do you think your teacher wants you to learn from this unit?

Interviews after lessons

Anything you especially enjoyed?

What do you think you were meant to be learning? How do you know?

Anything you've learned or thought about that you think is important or interesting?

Interviews following unit

Did you enjoy the work you did on.....? Why/why not?

What were the things you enjoyed the most? Why?

Was there anything you really didn't like? Why?

What were the things you worked hardest on?

What do you think were the really important things that you did in class about this topic?

What do you think were the really important things you learned? How did you learn them? Why are they important?

What else did you learn? How did that happen?

Did you learn to *do* anything new or get better at doing something? How?

What did your teacher do that helped you learn about this topic?

Was there anything you didn't you learn much from?

Can you tell me about (teacher focus...)

Was there anything you found hard? Why?

Did you do any assessments? How did you find them?

Do you think your teacher knows how much you've learned about this?

Is there anything you'd have liked to have done in this topic?

Is there anything that would make it better or easier to learn about? How would that make it better?

Anything else you'd like to tell me about doing this science topic?

Appendix D: Example of student questionnaire

Student Questionnaire on Science of Fitness Unit July 09

This questionnaire is designed to find out your opinions about the unit on fitness you have just completed.

You can look back through your book and sheets to help you remember if you want to.

Age: _____

Please circle:

Male/Female

Yr7/Yr8

1. What did you learn that was new or interesting during the science fitness unit?

2. What helped you learn these things?

3. What do you think were the most important things your teacher wanted you to learn during this unit?

4. What helped you learn these things?

5. List any other things you learned during this unit:

6. What did you enjoy most about this unit?

7. List anything you didn't like about this unit:

8. Below is a list of some things you or your class did in this topic. Tick the boxes that show how you feel:

	How much you liked this			How useful was this for your learning		
	Enjoyed a lot	Ok	Did not like	very useful	quite useful	not useful
Examining and drawing real heart (sheep)						
Examining and drawing real kidney (sheep)						
Examining and drawing real joints and muscles (chicken)						
Sticking pictures of organs where you thought they belonged in the body						
Measuring your chest and seeing how it changes as you breathe in and out						
Observing your hand as it sweated in a plastic bag						
Repeating the sweaty hand investigation to focus on predicting observing and explaining						
Measuring your lung capacity by blowing into the bottle in the water						
Examining and drawing the real heart and lungs connected together; seeing what happens when you squeeze the heart and blow into the lungs.						
Making a model of the lung						
Making and labelling a model of the heart						
Practicing recording accurate observations and diagrams by watching ice melt over a kettle						
Finding information about heart lungs ready for reports						
Writing a report on the heart						

Using internet and books to find answers to class questions about the heart and lungs						
Doing the investigation about pulse rates before and after exercise						
Planning and carrying out a your own fitness investigation						
Analysing the data using median, mean etc						
Presenting the results of your investigations						
The talk from the physio						
Doing the assessment activity on where organs are in the body						
Beginning to plan the investigations based on the physio's talk						

9. These are some of the things your teacher did during science lessons. Tick the boxes that are right for you:

	How useful was this for your learning?		
	very useful	quite useful	not useful
Getting you to think of things you wanted to know about fitness before the unit started			
Asked you to evaluate your work regularly and decide on goals for your next piece of work			
Pointed out parts of the real lungs and heart using the scientific names			
Asked you to think about which kind of investigation you learned most from			
Talks with your group when you're doing group work and asks your group questions to help you think about the task			
Makes sure that each group gets to do each task			
Asks you to talk with the person next to you on the mat to think of or check ideas			
Asks you questions that make you look carefully when you are observing things like the real heart			
Got the class's ideas for criteria for things like making labelled cross sectional diagram, or what was involved in a successful investigation			
Gave you information on the heart and the lungs to use for reports			
Helps you think about what you've found out by filling in sheets like "what I know about the lungs"			

Gets the class to practice things before doing it for yourself, like looking for key points in information by all highlighting the same article, or all practising analysing data before you had to do it for your own investigations			
Gives you sheets with questions and spaces to fill in to help you plan things like your heart report, or planning your investigation			
Makes you reflect on your learning in your learning journal			
Gets you to think about other people's work: what is good about it, what could be improved			
Gets you to think about your work: what is good about it, what could be improved			
Makes sure you hand in work and checks it			
Gives you written feedback on your work			
Makes you set new goals for the next piece of work			
Steps people for inappropriate behaviour			
Makes you reflect on how well you worked with your group			
Makes you work with a group she chooses			
Lets you work in a group you choose			
Talks with the class on the mat about what you're going to learn or what you have learnt			
Asks the class lots of questions and gets you to share your ideas			
Asks people who don't have their hands up to answer questions sometimes			

10. Here are some of the ideas and skills that were covered in this topic. Please tick the boxes that you agree with:

	Knew a lot about this already	Don't understand much about this	Understand this a bit better from doing this topic	Understand this really well from doing this topic
Where the major organs are in the body				
What the different parts of the heart are called				
What the heart does and how it works				
What the different parts of the lungs are called				
What the lungs do and how they work				
How to draw a labelled cross sectional diagram				
To record observations carefully when doing science				
Measuring pulse rates and recovery times				
Planning an investigation				
Recording data from your investigation in tables				
Interpreting data using mean median and mode				
Writing a conclusion explaining what your data shows				
What to include when presenting an investigation				

11. How much did you learn in this unit?

Nothing	Not much	Quite a lot	A lot

12. How much did you like this unit?

Not much	Some of it was ok	Quite a lot	A lot

If you can, say why:

13. How effective was your teacher at teaching this unit?

Not very effective	ok	Quite effective	Very effective

If you can, say why:

Do you think it's important to learn about things like how the body works and what it means for the body to keep fit?

Why?

Do you think it's important to learn about how to do a scientific investigation?

Why?

Any other comments about the fitness topic:

Thank you for completing this survey.

Appendix E: Participant information sheet and consent form

Participant Information Sheet for a Study of Science Education in New Zealand Schools in Years 7 and 8

Information for Principals

Researcher: Dayle Anderson, School of Mathematics, Statistics and Computer Science, Victoria University of Wellington

I am a lecturer in primary science and mathematics education at the Victoria University of Wellington College of Education. As part of my professional development I am currently involved in study toward a PhD in science education from the School of Mathematics, Statistics and Computer Science, Victoria University of Wellington. My study involves undertaking a research project leading to a thesis. The research I am undertaking is exploring effective practices for the teaching and learning of and about science in years 7 and 8. Your school has been invited to participate in this study because of the interest in and commitment of *teacher name* to teaching science at this level.

Participation in this research will involve you, *teacher name* and their students.

Involvement in this research for you personally would mean participating in an interview with me about aspects of your school concerning science education, such as the development and implementation of science policy, resourcing, field trips etc.

For *teacher name*, it means participating in interviews with me concerning her practices in planning and teaching science at years 7 and 8. It would also mean sharing and discussing written documentation such as science unit plans, long-term plans and school science policy. In addition I would like to spend time observing and audio taping science lessons in her classroom. I envisage that interviews would take place prior to the teaching of a science unit, at various points during the unit following observed science lessons, and at the end of the unit. This will depend, however, on the nature of their science programme. Interviews will focus on teaching decisions and their views about the effectiveness of different aspects of lessons, as well as factors that affect the delivery of science in their classroom.

Parental permission to participate in the research will be sought for all students in *name's* class. Parents will be provided with an information sheet similar to this one and asked to return a consent form allowing me to observe and audio tape as their child participates in science lessons. The form will also ask for consent to allow their child to participate both by responding to two questionnaires about their engagement with science at school and by taking part in interviews with me following science lessons. Not all students will be interviewed but permission will be sought from all parents in case their student is selected for interview. *Name* will be involved in the selection of students for interview. They will be asked to identify a list of students who they perceive to be average achievers in science, i.e. neither very high nor very low achievers in science. From this list four students, two male and two female, will be randomly selected to participate in interviews.

Responses collected will form the basis of my research project and will be put into a written report on an anonymous basis. All opinions and data will be reported in aggregated form in such a way that individual persons or organisations are not identifiable. It will not be possible for you to be identified personally. Pseudonyms will be used where necessary for individuals and schools. All material collected will be kept confidential. No other person besides my supervisor, Associate Professor Megan Clark, and myself will see the responses. It is intended that several articles will be submitted for publication in scholarly journals. Data

gathered from the research will be kept securely and destroyed two years after completion of the project.

I appreciate that participation in this study involves considerable commitment on your part. As a result of the research it is hoped that common features of effective practice can be identified and shared. At the end of the research you and your school will be provided with a summary of findings outlining those practices shown to be associated with effective teaching and learning in science at years 7 and 8. I hope you will see your contribution toward this research as valuable in informing and improving the practice and delivery of science education in New Zealand.

If you have any questions or would like to receive further information about the project, please contact me (see below) or my supervisor, Associate Professor Megan Clark, at the School of Mathematics, Statistics and Computer Science at Victoria University, P O Box 600, Wellington, phone 463-6738 or e-mail Megan.Clark@mcs.vuw.ac.nz

Signed:

Dayle Anderson
Lecturer in Primary Science and Mathematics,
Victoria University of Wellington College of Education.
e-mail: dayle.anderson@vuw.ac.nz
phone: 463-9630

**VICTORIA UNIVERSITY OF WELLINGTON
CONSENT TO PARTICIPATION IN RESEARCH
(Principals and Teachers)**

Science Education in New Zealand Schools in Years 7 and 8

I have been given and have understood an explanation of this research project. I have had an opportunity to ask questions and have them answered to my satisfaction. I understand that I may withdraw myself (or any information I have provided) from this project (before data collection and analysis is complete).

I understand that any information I provide will be kept confidential to the researcher, the supervisor and the published results will not use my name or that of my school, and that no opinions will be attributed to me in any way that will identify me or my school. I understand that the recording of interviews will be electronically wiped at the end of the project.

- ☐ I would like to receive a summary of the results of this research when it is completed.
- ☐ I agree to take part in this research

Signed: _____

Date: _____

Name : _____
(please print clearly)

School _____

**Study of Science Education in New Zealand Schools in Years 7 and 8
Information and Consent Form for Parents**

Researcher: Dayle Anderson, School of Mathematics, Statistics and Computer Science, Victoria University of Wellington

I am a lecturer in primary science and mathematics education at the Victoria University of Wellington College of Education. As part of my PhD research I am exploring effective practices for the teaching and learning of and about science in years 7 and 8. Your child's class has been invited to participate in this study because of their teacher's interest and expertise in science at this level.

If you consent, your child will be asked to complete an initial questionnaire about their science experience at school. There would also be a short questionnaire to be completed at the end of the forthcoming science unit asking them about aspects of their learning during the topic. Participation in this research will also involve your child's class being observed during science lessons. An audiotape of lessons or parts of lessons will be made for further analysis. In addition, four children from the class will be selected to participate in individual audio taped interviews. They will be interviewed before the unit about their interest and background in science and following the unit about their views on the science learning they have just done. I will also record brief conversations with them during lessons to identify their ideas about the activities they are doing. These would be very brief and timed so as not to disrupt their learning. The consent form below asks for permission for your child to participate in **all** the above aspects of the research.

All data will be reported in such a way that individual people or schools are not identifiable. It will not be possible for your child to be identified personally. All material collected will be kept confidential.

As a result of the research it is hoped that common features of good practice can be identified and shared. At the end of the year a summary of preliminary findings will be given to participating principals and teachers. A copy will also be sent home with each participating student. I hope you will see that allowing your child to contribute toward this research is valuable in informing and improving the practice and delivery of science education in New Zealand.

If you have any questions or would like to receive further information about the project, please contact me (see below) or my supervisor, Associate Professor Megan Clark, at the School of Mathematics, Statistics and Computer Science at Victoria University, P O Box 600, Wellington, phone (04)463-6738 or e-mail Megan.Clark@mcs.vuw.ac.nz

Dayle Anderson
Senior Lecturer in Primary Science and Mathematics Education,
Victoria University of Wellington College of Education.
e-mail: dayle.anderson@vuw.ac.nz
phone: (04)463-9630

I agree that _____ may take part in this project

Signed: _____

Name : _____ (please
print clearly)

Appendix F: Case 1 typical lesson

(*a measure of the proportion of class that appeared to be engaged in focus activity: 4: $\frac{3}{4}$ - whole class; 3: $\frac{1}{2}$ - $\frac{3}{4}$; 2: $\frac{1}{4}$ - $\frac{1}{2}$; 1: $< \frac{1}{4}$)

Date	Learning Experience	Duration	Content	Class engagement*
6 th March 51 minutes	Teacher led discussion setting focus for information gathering	5	Tides	4
	Individual or intermittent informal groups of 2-3 information gathering from books and internet. Teacher roves checking and supporting individuals	20	Tides	4
	Teacher led class discussion on information gathered	4	Spring and neap tides	4
	Teacher demonstrates model	3	Sun and moon's relationship to spring and neap tides	4
	Teacher led class discussion on information gathered	4	Tide periodicity	4
	Teacher led class discussion on information gathered	2	Importance of tide for rocky shore: food source, carrier of plankton	4
	Copying teacher made summary from OHT into books. Teacher monitors individual and class for understanding and tidiness	6	Spring, neap and regular tides periodicity, relationship of these to relative positions of sun and moon. Importance of tide as food source for rocky shore.	4
	Triathlon organisation	1 min		
	Copying teacher made summary from OHT into books.	6	Spring, neap and regular tides periodicity, relationship of these to relative positions of sun and moon. Importance of tide as food source for rocky shore.	4

Appendix G: Case 1 lesson log

Lesson	Major topics or activities	Specific aspects
5 th March	Class discussion Informal diagnostic assessment	Establishing topic as science Tides Ecological communities Food chains Classification and habitat of rocky shore creatures
6 th March	Class discussion and information gathering on tides	Spring and neap tides Periodicity Sun and moon's role Tide as food source for rocky shore creatures: zoo and phytoplankton
7 th March	Class discussion Class discussion and information gathering on identification/classification of rocky shore creatures	Tides(review) Characteristics of each group: identification
12 th March (Rocky shore field trip)	Free exploration	Rocky shore creatures and habitat
13 th March	Information gathering Assessment activity Class discussion (response to student query)	Classification Eating habits Food chains (diagnostic) Photosynthesis Plants make their own food using sunlight
27 th March	Class discussion Food chains ordering activity Class discussion Summative assessment activity (individual)	Tide as food source Zoo and phytoplankton Plants make own food Energy transfer Producers, herbivores, carnivores Detrital food chains Role of scavengers Food webs
29 th March	Class discussion	Energy transfer, food chains and webs (review) Environmental change and change agents

Appendix H: Case 1 sociocultural analysis of a typical lesson

Key: coloured areas indicate the activity was predominant for the duration
A number indicates frequency of use within the indicated period

Appendix I: Case 1 focus students' perceptions

In terms of	C1FS1	C1FS2	C1FS3	C1FS4
Worked hardest on	<ul style="list-style-type: none"> Finding out about creatures 	<ul style="list-style-type: none"> Trying to understand: "the thinking...I really want to understand it so I know what's happening" 	<ul style="list-style-type: none"> Could not identify anything she worked hard on 	<ul style="list-style-type: none"> Ordering the producers, herbivores and carnivores (coloured sheet ordering activity) Learning about food chains
Most important learning	<ul style="list-style-type: none"> How things live in their habitat 	<ul style="list-style-type: none"> About the creatures: what types they are, what they feed on; how they move and get their food Food chains need to start with a producer 	<ul style="list-style-type: none"> The moon, the sun and gravity work together to affect the tides 	<ul style="list-style-type: none"> Food chains: there has to be a producer
Other learning	<ul style="list-style-type: none"> That arrows indicate where the energy comes from The arrows are important because they show how you get the energy Energy comes from the sun. Energy is important for helping things live All food chains have to have a producer Animals need food from producers Producers make their own food Animals cannot make their own food Algae and plants are producers Living things live best in their own habitat The gravity of the moon pulls to cause the tides. There are spring tides and neap tides: these are higher and lower tides then normal(confused terms) 	<ul style="list-style-type: none"> The arrows are important in food chains Producers are seaweed and plankton Without producers everything else would die Producers provide food. Already knew about the moon's role in tides There are spring tides and neap tides: these are higher and lower tides The tide provides food for all of the life on the shore Creatures in high tide zones can get food from the sea less often Creatures in low tide zones depend more on the sea constantly for food To care for creatures in their environment 	<ul style="list-style-type: none"> The arrows are to do with energy flow, and show what eats what (Not sure what energy was or did) 	<ul style="list-style-type: none"> Detritus can start some food chains Without the sun there would be no life Seaweed and plankton are producers Producers feed others There are different types of plankton – phytoplankton and other ones Food chains occur in other environments as well as rocky shore Rocky shore creatures live hidden to avoid predators

Appendix J: Case 2 typical lesson

(*a measure of the proportion of class that appeared to be engaged in focus activity: 4: $\frac{3}{4}$ - whole class; 3: $\frac{1}{2}$ - $\frac{3}{4}$; 2: $\frac{1}{4}$ - $\frac{1}{2}$; 1: $< \frac{1}{4}$)

Date	Learning Experience		Duration	Content	Class engagement*
18 th May 38 mins	T2 introduces activity sheet reviewing development of question from wondering about problem or issue		3	A scientific question is testable and of relevance to society or individual: it helps develop new knowledge. A fair test question has only one variable and can be tested in the real world	4
	Practice first stage of process in supported stepwise way: identify problem /interest area	Think time	30 sec	Factors that cause problems with teeth	4
		Share ideas with partner	1	As above	4
		Share ideas with class	5	As above	4
	Practice second stage of process in supported stepwise way: identifying keywords to support information gathering to inform hypothesis	Think time	30 sec	Using keywords in information searches	4
		Sharing ideas for keywords for dental problems with partner	1	As above	3-4
		Share ideas with class	5	As above	3-4
	Ranking causes of dental problems		7	Ranking ideas in order of significance	4
	Practice next stage: Developing an investigable question from the problem	T2 gives model, child provides another model	4	A scientific question is testable and of relevance to society or individual: it helps develop new knowledge. A fair test question has only one variable and can be tested in the real world	4
		Students all practise with a partner	1	As above	4
		Share ideas with class	2	As above	4
		Individual practice	6	As above	4
	T2 gives feedback on class competence with developing scientific questions		2	As above	3

Appendix K: Case 2 lesson log

Lesson	Major topics or activities	Specific aspects of lesson [summarised from lesson transcripts (observed lessons) or teacher interviews, worksheets and written criteria (unobserved lessons)]
1 st May	Fair testing investigation process (Cereal and milk investigation)	Fair testing vocabulary Gathering scientific information to inform hypothesis Defining and identifying variables Importance of identifying all possible variables Selection of the independent variable for testing Developing a formal testable question
3 rd May (a) (Not observed)	Fair testing investigation process (Cereal and milk investigation)	Identifying variables Selection of independent variable Controlling variables Using scientific information to develop an informed hypothesis
3 rd May (b)	Features of a scientific hypothesis Fair testing investigation process (Cereal and milk investigation)	A scientific hypothesis is reasoned and situated in existing theory/experience Planning an investigation involves: <ul style="list-style-type: none"> • finding out what is known about the topic • developing an informed hypothesis • deciding on independent and controlled variables • gathering equipment • deciding on methodology • developing a way to record results
4 th May (not observed)	Practical investigation (Cereal and milk investigation)	Keeping variables constant Observing and recording results
15 th May	Testable questions (Health issues) Overview of fair test investigation process	A scientific question is testable and of relevance to society or individual: it helps develop new knowledge Identifying possible issues or problems Developing possible questions based on issues A fair test question has only one variable and can be tested in the real world
18 th May (a) (Not observed)	Testable questions Informed hypotheses (Health issues)	A scientific question is testable and of relevance to society or individual: it helps develop new knowledge. A hypothesis is informed by existing science ideas.
18 th May (b)	Improving testable questions (Health issues)	A scientific question is testable and of relevance to society or individual: it helps develop new knowledge. A fair test question has only one variable and must be able to be tested in the real world. Identifying possible issues or problems. Differentiating between questions that can be answered by looking for information and questions that frame an investigation. Identifying keywords for information searches Identifying significant issues. Developing formal testable questions with just one independent variable.
21 st May (a) Not observed	Improving testable questions (Health issues)	A testable question is open ended but measurable. The independent variable (what is being changed) is clear.

21 st May (b)	<p>Features of a fair test investigation</p> <p>Recording results Practical skills (Investigation of sugar levels in crackers)</p>	<p>Planning an investigation involves:</p> <ul style="list-style-type: none"> • finding out what is known about the topic • developing an informed hypothesis • deciding on independent and controlled variables • gathering equipment • deciding on methodology: what to measure and how. <p>Use of tables for recording results. Using paper funnels. Measuring accurately. Safe handling of spirit burner. Warming test tubes of liquid safely. Use of a plastic pipette for measuring small volumes. What to look for. Recording observations.</p>
22 nd May-22 nd June (taught by student teacher; not observed)	<p>(Completion of investigation of sugar levels in crackers)</p> <p>Carrying out a practical investigation Writing a conclusion (fat levels in milk)</p> <p>Presenting scientific investigations</p>	<p>Orderly accurate recording.</p> <p>A scientific conclusion:</p> <ul style="list-style-type: none"> • Makes a statement about how the results relate to the hypothesis. • Explains the results. • Identifies patterns or trends in results. • Identifies any surprises in the results. • Suggests reasons for results that are contrary to the hypothesis. • States what has been learnt and what could be done better. • Identifies areas for further research to explain results in more detail. • Identifies further investigations of interest. <p>Sections of a display should read in a logical order like a book.</p>
21 st June	Peer and self assessment	<p>Applying science fair judging criteria</p> <p>Giving feedback</p>

Appendix L: Case 2 sociocultural analysis of typical lesson

*Abbreviations:

TD	Teacher led class discussion
In	Teacher talk
GP	Group practice process step
GFB	Group feed back
S	Sharing ideas
T	Think time
IP	Individual practice of process
TfD	Teacher feedback on process step

Sci Info	Gathering scientific information
QI	Developing a science question from a real issue
Q	Developing specific measurable question

Key: coloured areas indicate the activity was predominant for the duration
A number indicates frequency of use within the indicated period

Appendix M: Case 2 focus students' perceptions

In terms of	C2FS1	C2FS2	C2FS3	C2FS4
Worked hardest on	<ul style="list-style-type: none"> Developing a method for her question that gave accurate results in all situations Writing the conclusion 	<ul style="list-style-type: none"> Deciding on a topic Writing the method 	<ul style="list-style-type: none"> Getting the hypothesis and conclusion "right" Doing the fair test 	<ul style="list-style-type: none"> Carrying out the investigation
Most important learning	<ul style="list-style-type: none"> Writing an "in-depth" hypothesis 	<ul style="list-style-type: none"> How to carry out and write up a fair test The integrity of fair testing: "like you don't change your hypothesis to match your conclusion" 	<ul style="list-style-type: none"> How to write a hypothesis, method, conclusion, control variables 	<ul style="list-style-type: none"> Everything has to be the same
Other learning	<ul style="list-style-type: none"> The need for accurate measurement and integrity in collecting data and for the development of a consistent methodology to ensure this 	<ul style="list-style-type: none"> How calcium gets into bones (from information search of science relating to own investigation) Devising criteria to help quantify results (devised a scale for flexibility/fragility of bone) 	<ul style="list-style-type: none"> An hypothesis has to have a reason why Procedural text is needed to describe methodology: "using words like next, and then, and after" A scientific question involves actually doing a test, not reading about it 	<ul style="list-style-type: none"> Use of passive voice for writing methodology: "you can't use any personal things like we and you" Scientific investigations require accurate recording of results Methodology develops with trialling

Appendix N: Case 3 typical lesson

(*a measure of the proportion of class that appeared to be engaged in focus activity: 4: $\frac{3}{4}$ - whole class; 3: $\frac{1}{2}$ - $\frac{3}{4}$; 2: $\frac{1}{4}$ - $\frac{1}{2}$; 1: $< \frac{1}{4}$)

Date	Learning Experience	Duration	Content	Class engagement*
21 st May Before play	Instructions and modelling of practical activities	6m	Equipment to be used and nature of each activity Repeating measurements for lung capacity activity	4
	Peer share	1m	Why scientists repeat measurements	4
	Instructions and modelling of practical activities	6m	How to calculate averages How to measure lung capacity: breathing deeply Expectations for observational drawing of lungs Equipment needed	4 3 as time goes on
	Diagnostic assessment of knowledge about the lungs Teacher organises practical activities	16m	Ideas about lungs: Location Function Structures Keeping them healthy	4 2 as they finish
	Group organisation and final instructions about equipment for models	4m		
	Group activities carousel 1	27m	1. Heart model making: heart structure and function; names of parts. 2. Teacher led sheep heart and lung observation and drawing. Focus on how oxygenated blood gets pumped by heart around body: thickness of heart muscle in lower chambers. Non oxygenated blood also gets pumped by heart to the lungs. Names of parts: trachea, atrium, aorta, ventricle, bronchial tubes, alveoli: linked loosely to function.	4
	Tidy up	6m		
	Karakia before play			

Appendix O: Case 3 lesson log

Lesson dates	Main topics or activities	Content [summarised from lesson transcripts (observed lessons) or teacher interviews and worksheets (unobserved lessons)]
April 30th (not observed)	Diagnostic assessment Initial student questions identified about fitness and the body.	Student interest, questions and knowledge about fitness and how the body works.
Prior to 14th May (not observed)	Observational drawing and diagrams.	Features of a labelled cross sectional diagram. How to interpret labelled diagrams.
14 th May	Observational drawing of fresh animal parts. Name and position of body parts. Sweaty hand investigation. Measuring chest expansion during breathing. Further student questions identified.	Detailed accurate recording of observations. Visible structures and nature of heart, kidneys and muscles. The heart is a muscle.
18 th May	Documenting an investigation: repeat of sweaty hand investigation. Review of observational drawings.	Method and results need to be recorded accurately. Features of labelled cross sectional diagrams.
19 th May (not observed)	Diagnostic assessment of knowledge about the heart.	Heart structure and function
21 st May am	Diagnostic assessment of knowledge about the lungs. Drawing and investigating fresh animal organs: heart and lung structure and function. Making models of heart.	Lung structure and function Oxygenated blood is pumped by the heart around the body. Non-oxygenated blood returned to the heart is pumped to lungs. Names of lung and heart structures and their function: connections between and nature of heart chambers, vessels and lungs.
21 st May pm	Features of reports providing scientific information.	Identify features of an expert report and apply to a report on kidney structure and function.
25 th May	Documenting an investigation: practise using observation of condensation formation. Information gathering about the heart	Science observations are objective: record what is actually observed. Diagrams need to be clear, clearly labelled and readable. Scientists need accurate evidence. Heart structure and function
26 th May (not observed)	Information gathering about the heart	Heart structure and function

Lesson dates	Main topics or activities	Content [summarised from lesson transcripts (observed lessons) or teacher interviews and worksheets (unobserved lessons)]
27 th May	Writing a scientific information report on the heart. Making heart model. Making lung model. Measuring lung capacity.	Heart structure and function. Heart structure and function. Lung structure and function. Repetition and averaging of measurements for validity. Finding patterns in data is a form of science investigation.
2 nd June (not observed)	Review of unit so far: wall display	Students describe activities carried out so far.
3 rd June	Review student questions from earlier in unit. Co-construction of heart and lung diagram. Students prepare formal answers for each student question. Review of methods for finding information in science used so far.	Observations of heart and lungs. How the heart and lungs are connected. Position, structures and functions for heart and lungs. Direct observation Making and using models Experimenting Reading from a number of sources
8 th June	Assessment of knowledge of heart	Heart structure and function
9 th -12 th June (not observed)	Completion of answers to student questions and heart and lung models. Gathering information for and completing scientific information report on lungs.	Heart and lung structure and function
15 th June	Assessment task	Heart and lung structure and function
16 th June	Investigating a question in a practical way. Groups begin to plan fitness related investigations.	Student question: how does asthma affect a sports person.
22 nd June	Groups plan fitness related investigations, including developing a table to record results.	Group question related to fitness based around measuring heart rate. Features of a successful investigation: science investigations need to be methodically planned, carried out and recorded; a table helps plan the investigation as well as record results in an orderly way
23 rd -26 th June	Interpreting numeric data: pattern seeking as a form of investigation. Students analyse, compare and report findings for lung capacity data for different groups (e.g., year group or gender comparisons)	Kinds of questions that can be explored by comparing data for different groups. Group learning skills. Mean, median and mode. Scientific data needs to be interpreted, made sense of and presented in forms that make sense to others.

Appendix P: Case 3 sociocultural analysis of typical lesson

Key: coloured areas indicate the activity was predominant for the duration
A number indicates frequency of use within the indicated period

Appendix Q: Case 3 focus students' perceptions

In terms of	C3FS1	C3FS2	C3FS3	C3FS4
Worked hardest on	<ul style="list-style-type: none"> Gathering information on lung function 	<ul style="list-style-type: none"> The heart rate fitness investigation, especially presenting findings 	<ul style="list-style-type: none"> The heart rate fitness investigation, because it was enjoyable 	<ul style="list-style-type: none"> Presenting findings from numerical data analysis
Most important learning	<ul style="list-style-type: none"> Lungs are not hollow, more sort of solid with little tubes Air goes through the bronchial trees, into the air sacs, the alveoli, where oxygen is absorbed into the capillaries around it The capillaries in the lungs swap stuff around: carbon dioxide is passed out, oxygen absorbed 	<ul style="list-style-type: none"> That the heart has four chambers and pumps blood around the body 	<ul style="list-style-type: none"> About the heart and lungs Names for aorta and pulmonary arteries Heart pumps 'unoxygenated' blood to lungs which return blood back to the heart to pump everywhere 	<ul style="list-style-type: none"> How to take your pulse The position of organs in the body, especially where the heart and lungs were
Other learning	<ul style="list-style-type: none"> The importance of detailed observation Muscles are made up of fibres supplied by blood The heart pumps de-oxygenated blood to the lungs. Oxygenated blood returns to the heart and is pumped by the heart round the body Oxygenated blood is a different colour from deoxygenated blood Diagrams use blue and red to show the two types of blood but these are not the true colours It takes 2000 repetitions for the muscles to learn to do a basic thing Year sixes have a faster resting 	<ul style="list-style-type: none"> Heart is connected to the lungs Lungs are 10cm away from collar bone Windpipe is 10cm long One lung is smaller than the other Heart is made of muscle tissue Blood needs oxygen in it If you want your body to be better at something you have to give it practice at the activity Science is wider than chemistry, it includes the body, fitness, water cycle and the environment <p>Confusions:</p> <ul style="list-style-type: none"> Still wonders why heart is 	<ul style="list-style-type: none"> Left atrium and left ventricle make one pump; right ventricle and right atrium make the other pump One tube connects the heart and the lungs and one carries the blood from the heart to the rest of the body (reversed names of these vessels) Diaphragm goes down and you get air, it goes up and you exhale How to use and analyse numerical data <p>Confusions:</p> <ul style="list-style-type: none"> Did not see lungs as oxygenating blood 	<ul style="list-style-type: none"> That you can breathe with one lung Which way the blood flows through your heart The heart pumps blood to the lungs and then to the places in the body that need oxygen and other things like vitamins Lungs take in oxygen from the atmosphere and oxygenates the blood in the alveoli Oxygen goes down the bronchial tubes to the bronchial branches to the alveoli and passes into the blood vessels

In terms of	C3FS1	C3FS2	C3FS3	C3FS4
	<p>pulse, but they're older, done more exercise, or have more energy</p> <ul style="list-style-type: none"> • How to organise a group • How to number crunch • How to set out data in a way that is understandable • To not work with your friends, but with people you work well with • In science it's very important to be able to work with anybody, and be able to come up with a solution • Organising is very important for science • You can't really be lazy and mistake one thing because then you have to start all over again: you've got to be very precise <p>Science is complex: you can't miss anything out because one slight change and it could be a whole different thing</p>	<p>required: blood could just go round the organs by itself</p> <ul style="list-style-type: none"> • Heart plays a role in oxygenating blood • We need oxygen to help us breathe 	<ul style="list-style-type: none"> • Unclear why body needs oxygenated blood 	